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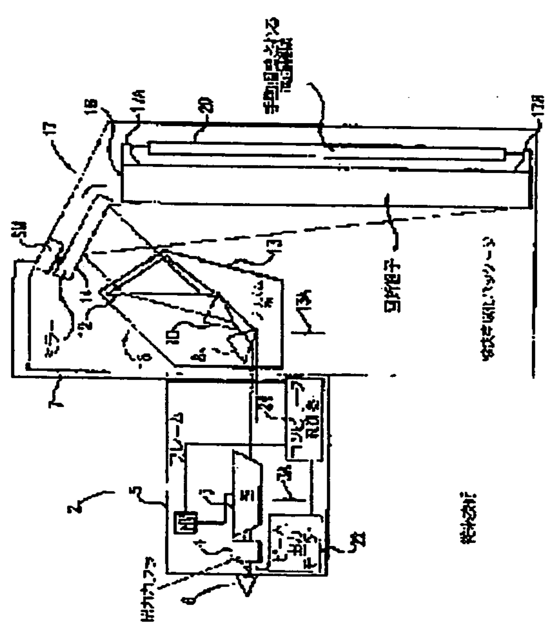
(54) NARROW-BAND LASER HAVING FINE WAVELENGTH CONTROL

(57)Abstract:
PROBLEM TO BE SOLVED: To provide a laser, particularly laser with feedback control for beam quality.
SOLUTION: Pulse energy is controlled by controlling discharge voltage, using feedback signals from a wavemeter. Wavelength is controlled by positioning an RMAX mirror in a line narrowing module. Bandwidth is controlled by adjusting the curvature of a diffraction grating in the line narrowing module. An optimal preferred embodiment here includes automatic feedback control of horizontal and vertical beam profiles by the automatic adjustment of a prism plate, on which beam expander prisms are located and automatic adjustment of an RMAX tilt. Another preferred embodiment includes automatic adjustment for the horizontal position of the laser chamber within the resonance cavity.



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CLAIMS

[Claim(s)]
[Claim 1] A) A laser frame and the laser room attached in the B aforementioned frame free [accommodation], C) Two extended electrodes which it was included by said interior of a room which defines a gain medium with the laser gas included by said interior of a room and the laser gas of D meantime, opened spacing, and were placed, E) A beam expander, an alignment mirror, and the line narrow-band-ized module containing a diffraction grating, F) Narrow-band discharge laser which is characterized by including a precise alignment means to adjust said output wavelength in the precision of less than 0.1 picometer, the wavemeter which detects G laser output beam wavelength, and H computer control machine and which generates an output laser beam.
[Claim 2] Said alignment means is laser according to claim 1 characterized by including at least one electrostrictive actuator made to **** said alignment mirror.
[Claim 3] Said alignment means is laser according to claim 1 characterized by including the pressure control means which increases or decreases the gas pressure of said line narrow-band-ized module.
[Claim 4] Said alignment means is laser according to claim 1 characterized by including a stepping motor and at least one electrostrictive actuator.
[Claim 5] Said alignment mirror is laser according to claim 1 characterized by being the mirror which can be deformed.
[Claim 6] Said alignment mirror is laser according to claim 1 characterized by being the divided mirror containing two or more mirror segments.
[Claim 7] Laser according to claim 1 characterized by including further the mirror location detection system which detects the pivot location of said alignment mirror.
[Claim 8] Said mirror location detection system is laser according to claim 7 characterized by including the location detection light source turned to said mirror, and the detector array which detects the reflection from said mirror.
[Claim 9] Said light source is laser according to claim 8 characterized by including a diode laser.
[Claim 10] Said light source is laser according to claim 8 characterized by including a mercury lamp.
[Claim 11] Laser according to claim 6 characterized by including further the mirror location detection system which detects the location of each mirror segment.
[Claim 12] Laser according to claim 1 characterized by including further the ************ unit which positions the aforementioned room horizontally as said gain medium is in a target location to a resonant cavity.
[Claim 13] A computer control machine is smart laser according to claim 2 characterized by being programmed to control the aforementioned room positioning machine unit in order to position the aforementioned room based on the feedback information from said wavemeter.
[Claim 14] Said prism beam expander is smart laser according to claim 1 characterized by including further the prism plate positioning machine unit which positions said prism plate, including two or more prism arranged on a prism plate.
[Claim 15] Said computer control machine is smart laser according to claim 4 characterized by being programmed to control said prism plate positioning machine unit in order to position said prism plate based on the feedback information from said wavemeter.

[Claim 16] Smart laser according to claim 1 characterized by including further the RMAX inclination positioning machine which makes said RMAX mirror incline in order to control the perpendicular space parameter of said output laser beam.
[Claim 17] Said computer control machine is smart laser according to claim 6 characterized by being programmed to control said inclination positioning machine in order to make said RMAX mirror incline based on the beam information from said wavemeter.
[Claim 18] The ************ unit which positions the aforementioned room horizontally according to the control signal from the A aforementioned computer control machine, including two or more prism with which said beam expander has been arranged on a movable prism plate, B) The prism plate positioning unit which positions said prism plate according to the control signal from said computer control machine, C) in order to adjust the nominal wavelength of said output beam based on the control signal from the RMAX inclination positioning machine which makes said RMAX mirror incline, and the D aforementioned computer control machine based on the control signal from said computer control machine Smart laser according to claim 1 characterized by including further the RMAX pivot positioning machine made [said RMAX mirror] to ****.
[Claim 19] Said diffraction-grating curve positioning machine is smart laser according to claim 1 characterized by including a stepping motor.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] a part of serial numbers 09/390,579 which applied for this invention on September 3, 1999 — it is continuation application. Especially this invention relates to the laser equipped with the feedback control of beam quality about laser.
[0002]
[Description of the Prior Art] A beam output needs to be controlled of the application about much laser exact. One of the applications of this kind of laser is the light source of integrated-circuit lithography. Current and KrF excimer laser are the light sources most chosen in the newest integrated-circuit lithography equipment. A volume is increased, and since efforts to generate a more precise integrated-circuit pattern are made, the specification of the light source is becoming severer. As for the general specification of 248-nanometer KrF laser, less than 0.1 picometer and energy dosage stability of assignment wavelength need [a bandwidth / about 0.6 picometer full width at half maximum and wavelength stability] about **0.5%. Furthermore, it is important to control the cross-section brightness value of a beam.
[0003] A part of conventional KrF excimer laser system feature used for drawing 1 by integrated-circuit lithography is shown. This system contains the laser frame structure 5 by which the laser room 3 containing two extended electrodes (not shown) have a gain medium between them was attached in the interior, the line narrow-band-ized module 7 (referred to as a "line narrow-band-ized package" or LNP) greatly shown in non-equilibrium, and the output coupler 4. The part of LNP of drawing 1 expresses the top view of LNP. Generally a beam cross section is a rectangle and is usually about 15 millimeters in 3.5 millimeter of ****, and height. With conventional equipment, each of the line narrow-band-ized module 7 and the output coupler module 4 (a partial reflection mirror is usually included) contains the frame attached so that it may not move to the laser frame structure 5. The optical member in the frame of an output coupler module and a line narrow-band-ized module is manually adjusted, in order to define the resonant cavity of laser. It is attached free [accommodation] in a laser frame so that precise positioning by hand control can be carried out within the resonant cavity defined in the **** and beam width direction sometimes shown by arrow-head 3A of drawing 1. By these accommodation, a laser engineer can arrange a resonant cavity in a gain medium and a straight line so that an optimal beam output parameter may be attained. For example, with the operation gestalt of this conventional technique, the prism beam expander 18 contains the prism 8, 10, and 12 attached on the prism plate 13. With conventional equipment, the prism plate 13 can be manually adjusted in the direction of arrow-head 13A as an alignment technique. by extending or contracting the bending device 20, conventional equipment imposes small larger or compressive force to Legs 17A and 17B, and is more stronger in the surface curve of a diffraction grating 16 again — or it includes carrying out a hand regulation to a more weaker concave surface configuration. Accommodation is performed mainly in order to control the bandwidth of an output beam. Otherwise, the conventional technique of forcing a diffraction-grating front face a concave surface configuration is indicated by U.S. Pat. No. 5,095,492.
[0004] The general excimer laser for lithography of the conventional technique by which current use is carried out incorporates two automatic feedback control, and adjusts pulse energy and the nominal wavelength. Pulse energy is controlled in feedback system by measuring output pulse energy with the beam output monitor 22, as shown in drawing 1 in order to adjust in the limitation aiming at it, and using these measured value and computer control machines 24, in order to control the high voltage applied to inter-electrode next. The beam output monitor 22 (called a wavemeter) also measures the nominal wavelength and the pulse-ized bandwidth of an output beam. In order to control the computer control machine 24 in the limitation aiming at the nominal wavelength of a beam, the pivot location of the alignment mirror 14 is adjusted using a stepping motor 15.
[0005] In conventional equipment, a stepping motor 15 can set up a step for the small increment to 1 micrometer. Lever linkage reduces these steps to 1/26, and decreases the size of a step to 38 nanometers. These linearity steps bring **** movement about the pivot line 17 to the alignment mirror 15 so that each of the minimum linearity step of a stepping motor may produce a **** operation of an about 0.47micro radian to a mirror 14. **** of an experience top 0.47micro radian produces change of about 0.05 picometer in the nominal wavelength of laser.
[0006]
[Problem(s) to be Solved by the Invention] What is called for is amelioration which brings about control of a laser beam output parameter quick [easier and] and exact.
[0007]
[Means for Solving the Problem] This invention offers the smart laser which has the automatic computer control of pulse energy, wavelength, and a bandwidth using the feedback signal from a wavemeter. Pulse energy is controlled by controlling discharge voltage. Wavelength is controlled by very precise and prompt positioning of the RMAX mirror of a line narrow-band-ized module. A bandwidth is controlled by adjusting the curve of the diffraction grating of a line narrow-band-ized module. The best operation gestalt includes the automatic feedback control of the horizontal and straight beam cross section by automatic regulation with the prism plate with which beam expansion prism was placed, and a RMAX inclination. Moreover, the another best operation gestalt includes regulating the horizontal position of a laser room automatically in a resonant cavity. In the best operation gestalt, the feedback signal from a wavelength monitor is used for positioning a RMAX mirror. In other best operation gestalten, another laser beam reflected on the photodiode array from the RMAX mirror is used for positioning of a RMAX mirror.
[0008]
[Embodiment of the Invention] The best operation gestalt of this invention is explained by by referring to a drawing.

(The 1st best operation gestalt) The outline of the combination block diagram showing the 1st best operation gestalt of this invention is shown in drawing 2 . This drawing shows the important amelioration exceeding the conventional technique which automates the alignment of a laser room and a member, in order to prepare the instant control improved sharply [an important laser beam parameter]. In new laser frame 5A, a ****** stepping motor is added on it and the horizontal position of ** is automatically adjusted in the direction of 3A. New LNP7A contains the prism plate stepping motor 32, the RMAX inclination stepping motor 34, and the diffraction-grating curve motor 30. All these stepping motors are controlled by computer control machine 24A.
[0009] (Bidirectional automatic control of a diffraction-grating surface curve) The diffraction-grating curve stepping motor 30 is added in order to control the curve of a diffraction grating 16. New bending device design 20A is contained in a system, and it has the capacity to apply the tension which draws near the legs 17A and 17B of each other, in order to make a convex curve on the compressive force which extends Legs 17A and 17B outside in order to make a concave curve on the front face on which wire drawing of the diffraction grating 16 was carried out, or the front face on which wire drawing of the diffraction grating 16 was carried out. Control of a motor 30 is performed by the computer control machine 24. The fundamental components and functional description about actuation of a diffraction-grating bending device are shown in drawing 3 A, and 3B and 3C. Drawing 3 A shows the diffraction-grating assembly with which the bending force is not applied to the diffraction grating, although the congruence directional-control unit is attached. The piston 49 fixed to a diffraction grating 16, left end plate 17B, right end plate 17A, the compression spring case 48, the left compression spring 50, the right compression spring 51, the accommodation shaft 44, and the accommodation shaft 44 by the pin is illustrated. The accommodation shaft 44 contains chasing die-length 44A (the die length of 1 / 4-28 UNF-2B x1.38) which engages with the chasing slot of right end plate 17A. In the conditions of drawing 3 A, both springs are in the condition that the equal compressive force which offsets each other is applied, or the load is not hung on both springs. The curve on the front face of a diffraction grating is adjusted by rotating a shaft 44. By screwing in a shaft 44 in a case 48, the left compression spring 50 is compressed to the left-hand side and the piston 49 of a case 48 so that two arrow heads in the case 48 of drawing 3 B show. Compressive force is effective in the end plates 17A and 17B of two sheets being pushed, and a case 48 being pulled apart on the left, as push and an arrow head 56 show to the right in a rod 44. This has the operation which bends the front face of a diffraction grating 1 in a concave surface configuration, as shown in a line 58.
[0010] Contrary to this, by thrusting in the direction from which a shaft 44 is taken out out of a case 48, the right compression spring 51 is compressed to the right-hand side and the piston 49 of a case 48 so that two arrow heads in the case 48 of drawing 3 C show. A rod 44 is lengthened on the left and it lengthens a case 48 on the right, and compressive force has the effectiveness which draws near the end plates 17A and 17B of two sheets, as an arrow head 57 shows. This has the operation which makes the front face of a diffraction grating 1 deform into a convex configuration, as shown in a line 59. With this best operation gestalt, a rod 44 has chasing per [28] inch, and a spring is 52pound in specific weight dry per inch. An operator can adjust extremely the curve on the front face of a diffraction grating to a precision by this design.
[0011] Drawing 4 is the perspective view showing diffraction-grating assembly 16A which the applicant and the joint applicant manufactured. An assembly The diffraction-grating end plate 42 (the diffraction grating 16 is pasted) of 16 or 2 diffraction gratings, Right bidirectional bandwidth control end plate 17A, a lock nut 56, the Invar floor plate 53 pasted up on the diffraction grating 16, the alignment rod 44, the linearity bearing 62 of 64 or 2 sockets, the compression spring case 48, the thrust bearing 63 of 51 or 2 right compression spring, The piston 49 stopped by the rod 44 by the pin, the left compression spring 50, the migration limited piston 57 stopped by the rod 44 by the pin, radial ball bearing 54, a pivot 55, and left bandwidth control end plate 17B are included.
[0012] Drawing 5 is LNP. It is drawing which cut off a part of front face of 7A. Drawing shows diffraction-grating assembly 16A of bidirectional bulge control. Moreover, as mentioned above in relation to drawing 3 A, and 3B and 3C, the diffraction-grating bulge control stepping motor 30 which controls the curve of the front face where a line was drawn on the diffraction grating 16 from a concave surface to a convex is also shown. Although drawing 5 also shows the prism plate accommodation motor 32, the motor control of the RMAX mirror 14 is not shown. The bottom view of line narrow-band-ized package 7A is shown in drawing 7 A (drawing seen toward LNP from the transverse plane, i.e., laser), and drawing 7 B (from a rear face). It turns out that the diffraction-grating curve stepping motor 30 is attached in the tie-down plate. 34 and a RMAX stepping alignment motor are respectively shown [the prism plate motor] for 32 and a RMAX inclination motor by 15. The RMAX stepping interlock mechanism in this operation gestalt is substantially [as the conventional device described by the term of the conventional technique] the same. A lever device reduces a linearity stepping driver to 1/26, and prepares the 0.038-micron minimum step. The in-and-out port of the beam to LNP is shown by 60.
[0013] (Position control of a prism plate) The position control of the prism plate 13 is drawn on cutting drawing 5 A which also shows the prism plate stepping motor 32. A stepping motor 32 is also attached in the tie-down plate, and is shown in drawing 7 A and drawing 7 B. Control of a motor 32 is performed by the computer control machine 24.
[0014] (Automatic RMAX inclination control) The RMAX inclination control stepping motor is shown by 34 in drawing 7 A, drawing 7 B, drawing 6 A, drawing 6 C, and drawing 6 D. The inclination of the RMAX mirror 14 is prepared by the RMAX stepping motor 34 by which this is also controlled by the computer control machine 24. The inclination of a mirror 14 determines the perpendicular include angle of light reflected within a resonant cavity.
[0015] (Wavelength selection by the alignment mirror) In this best operation gestalt, selection of wavelength is prepared by the stepping motor 15 and sets up the horizontal position of the pivot of the alignment mirror 14 based on the command from the computer control machine 24 using the feedback wavelength information from the wavemeter 22 by the conventional technique indicated in the term of the conventional technique of this specification.
[0016] (Automatic room position control) This 1st best operation gestalt contains the ****** stepping motor 36 which shows the horizontal position (namely, horizontal position of the gain medium included by the laser room) of the laser room 3 to drawing 2 which is automatically adjusted in the direction perpendicular to a beam 6 about a frame 5 (the output coupler 4 and the line narrow-band-ized package 7 are attached there).
[0017] (Control) In order to maintain within limits aimed at a beam parameter based on the feedback signal from a wavemeter 22, as for computer control machine 24A shown in drawing 2 , it is desirable to be programmed by the control algorithm which controls motors 36, 32, 34, and 30 in addition to a motor 15. An easy approach is scanning the item in the predetermined range in order to ask for the location which keeps constant all the locations except one place (for example, ****** stepping motor), looks at parameters, such as a pulse energy output, pulse energy constancy, and a bandwidth, and produces the optimal beam engine performance. A computer is programmable to perform these scans at directions of an operator or the predetermined fixed spacing. If a wavemeter detects a certain fall in beam quality, it is also possible to program a computer in quest of the optimal

location to scan one or this kind beyond it.
[0018] Moreover, it is known during burst mode actuation of laser that a beam parameter will change as a function of a pulse number (namely, time amount from initiation of a burst) (for example, when laser is operated so that a burst of the pulse of the quiescent time for 0.3 seconds may be continuously generated 300 pulses at a rate of per second 1000 pulse). In order to soften or compensate these change, a computer control machine is programmable to adjust one or the stepping motor beyond it as a function of the time amount from a burst start.
[0019] (Specific optimization technique) in order to judge the optimal laser engine performance with the one best engine-performance optimization technique — several merits — M is defined. Subsequently, accommodation for making the number of merits into max is performed. This value is calculated using the input from the sensor which measures a beam in the real time. These sensors usually give values, such as energy constancy, laser effectiveness (output energy over input voltage), a bandwidth, beam width, a beam symmetry, and positioning GU constancy. Generally the best number of merits will become what combined some most important parameters that become the key of a success in the case of application to a lithography exposure etc. For example, the number of merits will become M= pulse energy / charge electrical potential difference, or M=E, when it is thought that only the laser effectiveness measured by pulse energy / charge electrical potential difference (E) is important.
[0020] When the space symmetric property (horizontal) SH is judged in addition to E, SH must be measured and a weighting factor WSH must be given. It becomes zero when perfectly symmetrical. Therefore, the new formula to the number of merits is as follows.
M=E-(WSH)(SH)
Next, accommodation which makes M min is performed. Similarly, the number M of merits can also obtain perpendicular symmetry (VS), a bandwidth (B), the stability (WS) of wavelength, the stability (DS) of dosage, etc. as a function of other parameters. In this case, the formula of M is as follows.
M=E-(WSH)(SH)-(WSV)(SV)-(WB)(B)-(WWS)(WS)-(WDS)(DS)
In order to attain the minimum number M of merits, a computer adjusts a stepping motor location, measures E, SH, SV, B, WS, and DS, and is programmed also here again to apply a weighting factor.
[0021] Many techniques which optimize the laser engine performance in consideration of some kinds mentioned above of parameters are known. the one best operation gestalt comes out, and this is described by the work "the technique of numerical analysis, and the technique of science count" besides a W.H. press of Cambridge University Press 1990 issue, and is quoted there. If it says simply, it will be chosen for accommodation of the group of initial setting. Probably, there is a configuration (one configuration is the value of the lot for accommodation) of a number with more one than the number of the parameters adjusted. Accommodation is repeatedly set as each configuration [once], and the number of merits is measured. The configuration of the worst merit is refused there and changed to the new configuration near the optimal configuration. If it continues repeatedly, by the time it can choose which of a configuration as optimal thing, a configuration will approach mutually. At former work, the applicant appeared in finding optimum about 10 times repeatedly enough, and has discovered a certain thing. Although a bottom inclination simplex method is a reliable technique, if very rapid convergence is required, other techniques known well can also be used.
[0022] (Measurement of an additional beam parameter) As the term of the conventional technique described, the lithography laser of the conventional technique was prepared with the wavemeter which measures pulse energy wavelength and a bandwidth at high speed. A parameter is usually measured about each of the laser pulse of a 1000 to 2000 Hertz repetition rate. These people prepared the optical array as shown in drawing 8 , in order to measure various beam parameters. The image of the laser beam in output coupler opening is optically relayed to a fluorescent screen through a lens 70, and a beam parameter including a perpendicular and level symmetry is measured on a fluorescent screen 74 using the CCD camera which carried out focusing, as shown in drawing 8 . A fluorescent screen changes the ultraviolet-rays light from laser into the light supervised by the CCD camera. The analog output from a camera is changed into digital one with a video frame incorporation vessel, and the output of a frame incorporation machine is analyzed by the computer processor.
[0023] In relation to said work, these people were also able to supervise beam emission, current-beam-position doubling, and current-beam-position doubling stability using the 2nd beam path which passes along a lens 72 as shown in drawing 8 . In this case, a lens 72 doubles the focus of a laser beam on a fluorescent screen 74, and it is located so that a completely parallel light which carries out incidence to a lens may appear as a diffraction marginal spot with a fluorescent screen. Therefore, the magnitude of a spot is the scale of beam emission and a motion of a spot is the measure of the change of current-beam-position doubling. In order to optimize the laser engine performance in consideration of these parameters, these additional parameters can be used in this invention.
[0024] (Control of wavelength) The general approach of controlling wavelength in laser lithography is building the laser control system which the operator of laser specifies wavelength and can make the specified wavelength automatically by the feedback program. This is usually desirable, it is because laser is usually operated by burst of the short pulse of 100 pulses by the repetition rate of per second 1000 pulse including the pause during the burst of several [1/] to several [for 1 second] seconds when producing an integrated circuit, consequently the wavelength of a beam is because it changes by modification of a gain medium and the optic for laser system.
[0025] At the lithography laser system of the conventional technique shown in drawing 1 , while the wavelength of a laser output beam is supervised with the output monitor 22, the wavelength monitor which combined the diffraction grating and the etalon supervises wavelength in the precision of about 0.1 picometer. A monitor is periodically proofread to the well-known absorption line. This kind of conventional wavemeter is indicated in the U.S. patent No. 5,978,334, and is taken in by this case as reference reference. For example, the operator of laser can program the computer control machine 24 to control laser wavelength to 248,321.30 picometer. In order to maintain the measured value of wavelength from a monitor 22 to 248,321.wavelength 30 picometer aiming at the wavelength measured by the monitor 22 using a receipt and its information, a controller 24 adjusts a stepping motor 15 and is made to **** a mirror 14 so that wavelength may increase or decrease. For the smallest increment of a motion of this conventional stepping motor 15, about 0.05 picometer of output wavelength changes.
[0026] The best operation gestalt for which wavelength control more precise than (more precise wavelength control) is prepared is shown in drawing 9 . With this operation gestalt, the conventional stepping motor 15 is used in order to make Miller machine style 14a which was constituted in order to make alignment mirror 14C **** only once [of rotation] (related with the perpendicular pivot line shown by 82) and which contains electrostrictive actuator 14B inside **** (related with the perpendicular pivot line shown by 80). The dimension of mirror 14C is abbreviation 1.5 inch x3.0 inch, and thickness is about 2.5 inches. Moreover, weight is about 2 unciae. The small electrostrictive actuator is marketed from the supply origin of a FIJIKU

instrument etc. for the mirrors of this size, and can prepare the **** range of 0.1 radians in a very precise precision in a 5000 Hertz repetition rate. These alignment mirror systems are equipped with the electronic drive unit which supplies a high-voltage signal to a piezoelectric motor.
[0027] With this best operation gestalt, computer control machine 24A is programmed to control both a stepping motor 15 and piezo-electric unit 14B. Electrostrictive actuator 14B can rotate mirror 14C in a very precise precision so that it can align in a precision much higher than the precision of about 0.1 picometer in which a wavemeter has laser. It is attached in a stepping motor 15 and a serial, linearity expansion and contraction of a piezo-electric drive are made to act, and a RMAX mirror is made, as for electrostrictive actuator 14D, to **** about pivot line 80A in other arrangement shown in drawing 9 A.
[0028] (Preliminary alignment) One of the problems in the conventional wavelength alignment arrangement is feedback system, and that is because laser control will need some pulses by the time it can perform accommodation required in order to generate target wavelength. Drawing 11 shows the operation gestalt designed especially in order to align in advance of laser actuation. It is reflected from mirror 14C and focusing of the collimated beam 84 from the diode laser system 86 is carried out to the thin line on the photodiode array 90 used in order to measure the pivot location of mirror 14C with the cylindrical shape lens 88. In a feedback configuration, the mirror positioning processor 92 uses the information from PDA90, and in order to generate the **** include angle of the mirror ordered from computer control machine 24A, it controls the location of a stepping motor 15 and electrostrictive actuator 14B. Since a target wavelength output is generated, computer control machine 24A is programmed to establish the correlation matrix of PDA output data and wavelength to be able to require a suitable mirror location beforehand.
[0029] A collimated beam 84 can be connected with the single mode fiber 96 with a core diameter of about 2.5 microns, and can be prepared by the diode laser system 86 containing the diode laser 94 which operates by 670 nanometers. The light which came out of the fiber 96 is prepared by the collimated beam 84 with an aspheric lens 98. The focal distance of a lens 98 is about 20 millimeters, therefore brings about the beam 84 with a diameter of about 5 millimeters. Emission of this beam is about expressed by the degree type.

$$\frac{\lambda}{D} \qquad \theta = 1.22$$

Here, lambda is 670 nanometers in wavelength, and D is 5 millimeters in beam diameter, therefore emission is theta= 1.63xten - four radians of abbreviation. Focusing of this low emission beam is carried out in the distance of about 500 millimeters on a diode array 90 with a lens 88. The spot size in PDA is about 82 microns. The best PDA has the pixel of 2048 at intervals of 14 microns. Therefore, a spot covers about 6 pixels. The operator of laser desires to control laser by **0.1 picometer or precision beyond it on target wavelength. Change 1 picometer of the wavelength of KrF laser is equivalent to the about 9.9micro radian of change of the location in which **** of a mirror 14 is free.
[0030] The distance between a mirror 14 and PDA90 is about 300 millimeters. The inclination of the 9.9micro radian of a mirror 14 produces a 5.94-micron gap of the beam spot on PDA90. The thickness of a spot is about 82 microns. If it is going to attain the precision of a 0.6-micron gap (it is equivalent to a gap of the wavelength of 0.1 picometer), it is necessary to supervise the brightness of a pixel along with a steep slope beam spot part (the near mesial magnitude part of a spot). As for a processor 92, being programmed to perform this is desirable. Each pixel has the brightness response of 256 level to a commercial cheap PDA array. Precision can be improved and it can be made to improve further also by averaging some pixels of a steep slope spot part by continued and averaging to the time interval which can use many brightness. Another best approach is shown in drawing 11 A. Here, the middle fixed mirror 100 reflects a beam 4 times from mirror 14C, doubles a gap four to the wavelength of the picometer by that cause, and produces a 24-micron gap. Therefore, fluctuation of 0.1 picometer corresponds to a gap of the 2.4-micron beam spot, and it becomes easy far that this looks at change of the pixel brightness of the steep slope edge of a spot.
[0031] (Chirp) The temporal response of wavelength is called the "chirp" or the "chirp of wavelength" among these contractors. These change takes place very quickly with the time scale of less than [0.001 seconds or it]. As mentioned above, a chirp may happen according to many factors, such as a thermal effect, the sound effect, etc. of the interior of a room or an optical member. In almost all cases, a chirp is not welcomed, but high-speed control of the wavelength which this invention offers can be used for pressing down a chirp to min. Furthermore, there is a situation that a certain controlled chirp is needed, and then, a chirp is programmed in order to use computer control machine 24A and a processor 92. Drawing 11 and drawing 11 A and the main advantages of the system shown in drawing 11 B are being able to set up a mirror location in advance of laser actuation based on the past proofreading data.
[0032] Laser gas circulates through between the electrodes with which about 3kW is periodically emitted in little laser gas in the discharge-in-gases laser which is operating by 5000 Hertz from 1000 Hertz of pulse rates at the rate which is 100 meters/s of maxes, and he needs to understand that prism and other optical members are ** made into an ultraviolet-rays light pulse with the average energy changed from zero watt to about 50W. Therefore, the effectiveness of thermal and others can produce a very slight change of wavelength, and an operator can be tried in order to control it by 0.1 picometer or precision not more than it. The operation gestalt shown in drawing 11 enables an operator to adjust the alignment mirror 146, in order to compensate distortion of the wavelength produced according to such effectiveness. When the chirp pattern which does not have the need corresponding to the specific mode of laser actuation is detected, the computer processors 24A and 92 can be programmed to control alignment mirror 14C beforehand, in order to make a chirp into min.
[0033] (Mirror which can be deformed) Drawing 10 shows the another best operation gestalt of this invention. Although the operation gestalt in this case is the same as that of what is shown in drawing 9 and drawing 11 almost, mirror 14C of drawing 9 and the operation gestalt of drawing 11 is divided into five segment 14C 1, 2, 3, 4, and 5, and they differ at a point. Each segment is controlled by the piezo-electric driver of itself. In order to make the include angle aiming at a mirror turn to, and since offset is the multiple of wavelength when a mirror offsets about a phase, as for a piezo-electric member, it is desirable to prepare a ramp, a point, and a piston. This kind of division mirror is indicated in U.S. Pat. No. 4,944,580 of July 31, 1990 issue, and is taken in by this case as reference reference. Since each divided mirror is lightweight much, far high-speed control is possible. A current piezo-electric technique enables accommodation in which **** in a 10,000 Hertz [a maximum of] repetition rate is free.
[0034] As shown in drawing 10 A, the location of these mirrors is made parallel with a lens 118, and can be supervised using the source of mercury light from the lamp 114 which passes a slit 116 reflected from the mirror 120 located above a laser beam. A mercury beam is expanded through the beam expansion prism 8, 10, and 12, and focusing is carried out by the mirror array 122 on the PDA array 124. The mirror of a piezo-electric drive of the mold shown in drawing 10 which can be deformed is available from supply [many] origin, such as a SAMOTO Rex corporation of the California San Diego whereabouts.

[0035] (Pressure modulation) The option which prepares very precise alignment of wavelength is controlling the gas pressure in LNP. As for LNP, purifying with nitrogen is desirable. In the past, the nitrogen pressure force has been kept constant by the pressure exceeding atmospheric pressure very only. Change of the nitrogen pressure force changes a refractive index, and, thereby, changes the incident angle on a diffraction grating very only. Since the flow of purge gas is the continuous flow which passes along LNP, a pressure is changeable using the control bulb of inlet-port purification Rhine or outlet purification Rhine. The response to it is comparatively slow. A rapid change of a pressure can be prepared as shown in drawing 12 using the proportionality solenoid actuator 110 and bellows 112. Moreover, other purge gas, such as helium, can be used instead of nitrogen.

[0036] Although this invention has been indicated and explained with reference to a specific operation gestalt, it is clear to this contractor that it is easy a related principle's to use for other operation gestalten of a number many. For example, each stepping motor is exchangeable for alternative positioning units, such as an alternating current, a DC motor, oil pressure, or an air pointing device. Many approaches of controlling pointing devices other than the proposed computer program can also be used. One or the stepping motor beyond it can be applied to an output coupler, and an output coupler can be automatically positioned using the same technique as the above-mentioned explanation about a RMAX mirror. As three strong permanent magnets are shown in drawing 6, one can be replaced with a piston and the remainder can be used as a substitute of two compression spring. A magnet 60 is fixed to a rod 4 and magnets 62 and 64 are fixed to a case 8. A rod 4 passes the hole of magnets 62 and 64. The effectiveness which thrusts a rod 4 into the outside in a case 8 from a case is substantially [as the above-mentioned effectiveness] the same. The curve of a diffraction grating can be attained even if it uses any of many techniques. For example, compression or tension can be applied to many points, any forms can be made on the target fact, and these forms can be applied to feedback computer control. Mirrors 14 may be mirrors of other molds which can be deformed, such as a mirror which can be deformed smooth, and beam expansion may be a total reflection beam expansion mold. Therefore, this invention is limited only in the range shown in separate paragraph generic claims and those legal equivalent range.

[Translation done.]

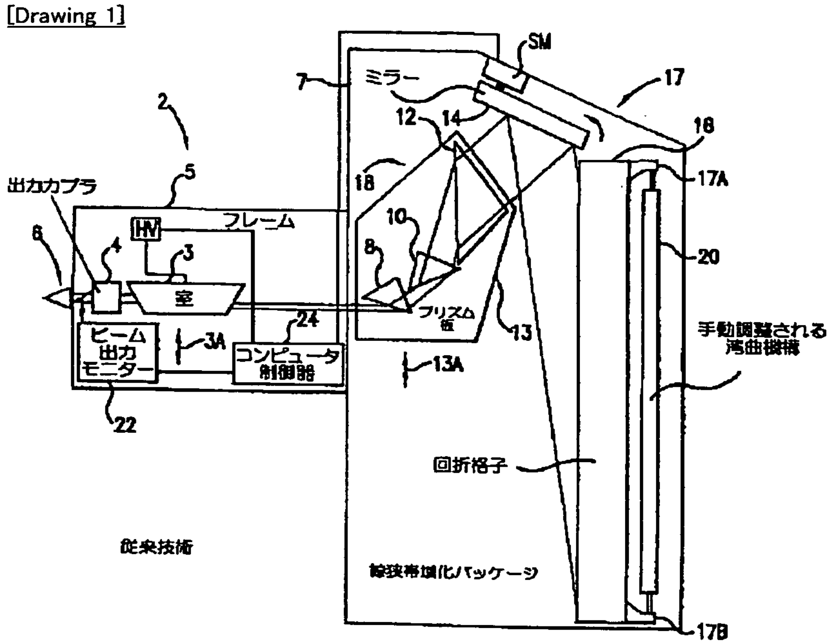
DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is drawing showing the configuration of the conventional narrow-band laser.
[Drawing 2] It is drawing showing the best operation gestalt of this invention.
[Drawing 3 A] It is drawing showing the working principle of a diffraction-grating bending device.
[Drawing 3 B] It is drawing showing the working principle of a diffraction-grating bending device.
[Drawing 3 C] It is drawing showing the working principle of a diffraction-grating bending device.
[Drawing 4] It is the prog of a bending device.
[Drawing 5] It is drawing showing some descriptions of the best operation gestalt of drawing 2 .
[Drawing 6 A] It is drawing showing other descriptions of the operation gestalt of drawing 2 .
[Drawing 6 B] It is drawing showing other descriptions of the operation gestalt of drawing 2 .
[Drawing 6 C] It is drawing showing other descriptions of the operation gestalt of drawing 2 .
[Drawing 6 D] It is drawing showing other descriptions of the operation gestalt of drawing 2 .
[Drawing 7 A] It is the pars-basilaris-ossis-occipitalis prog of the line narrow-band-ized module in the operation gestalt of drawing 2 .
[Drawing 7 B] It is the pars-basilaris-ossis-occipitalis prog of the line narrow-band-ized module in the operation gestalt of drawing 2 .
[Drawing 8] It is drawing showing the optical array for measuring the selected beam parameter.
[Drawing 9] It is drawing showing the description of the best operation gestalt.
[Drawing 9 A] It is drawing showing the description of the best operation gestalt.
[Drawing 10] It is drawing showing an operation gestalt with divided RMAX.
[Drawing 10 A] It is drawing showing the operation gestalt of drawing 10 , and the same operation gestalt.
[Drawing 11] It is drawing showing the description of other best operation gestalten.
[Drawing 11 A] It is drawing showing the description of other best operation gestalten.
[Drawing 11 B] It is drawing showing the description of other best operation gestalten.
[Drawing 12] It is drawing showing LNP by which pressure control was carried out.
[Description of Notations]
3 Laser Room
3A The direction of beam width
4 Output Coupler
5 Laser Frame Structure
6 Beam
7 Line Narrow-band-ized Module
8 Prism
10 Prism
12 Prism
13 Prism Plate
13A The accommodation direction of a prism plate
14 Alignment Mirror
15 Stepping Motor
16 Diffraction Grating
17 Pivot Line
17A Leg
17B Leg
18 Prism Beam Expander
20 Bending Device
22 Beam Output Monitor
24 Computer Control Machine

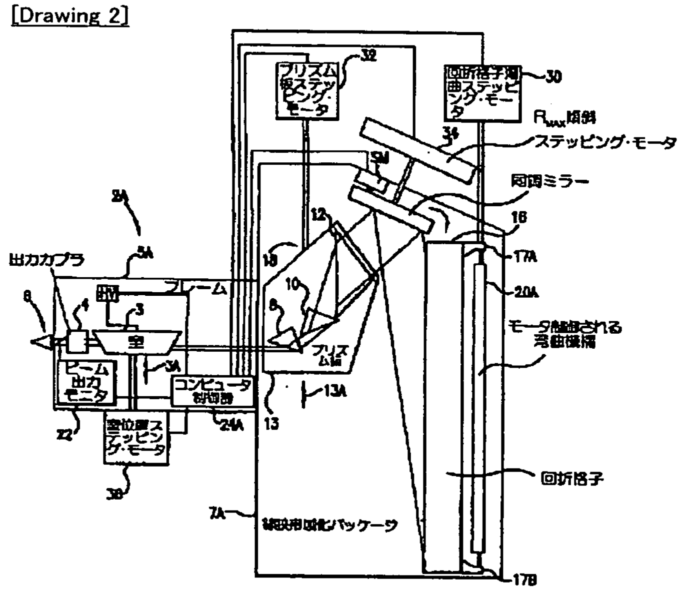
[Translation done.]

DRAWINGS

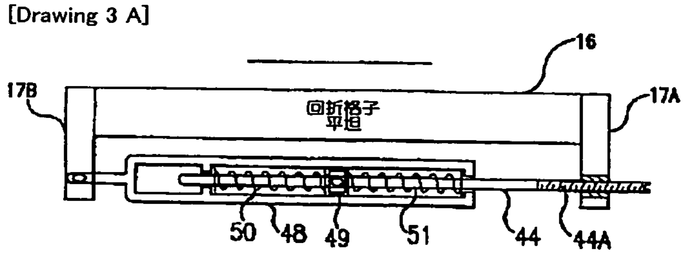
[Drawing 1]



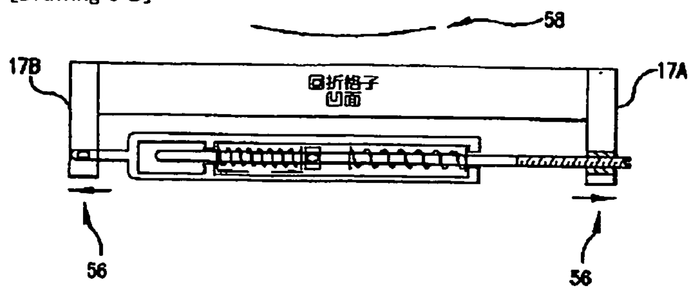
[Drawing 2]



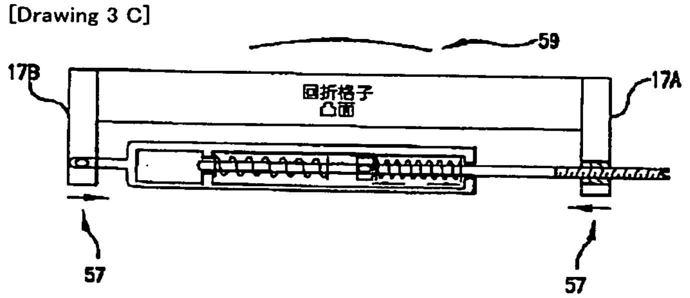
[Drawing 3 A]



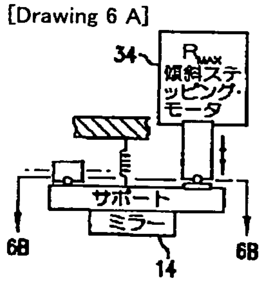
[Drawing 3 B]



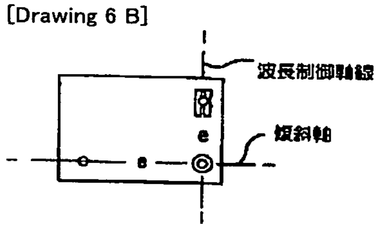
[Drawing 3 C]



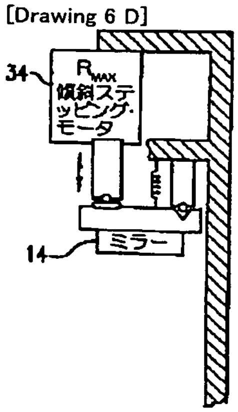
[Drawing 6 A]



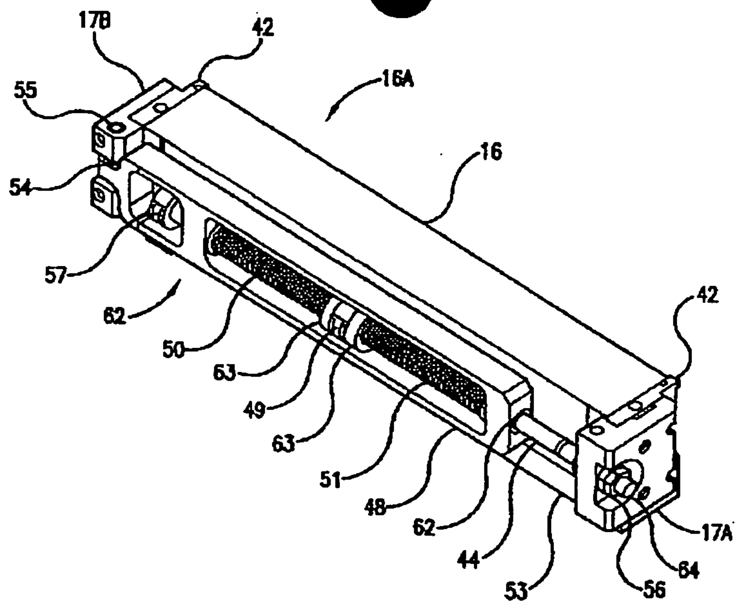
[Drawing 6 B]



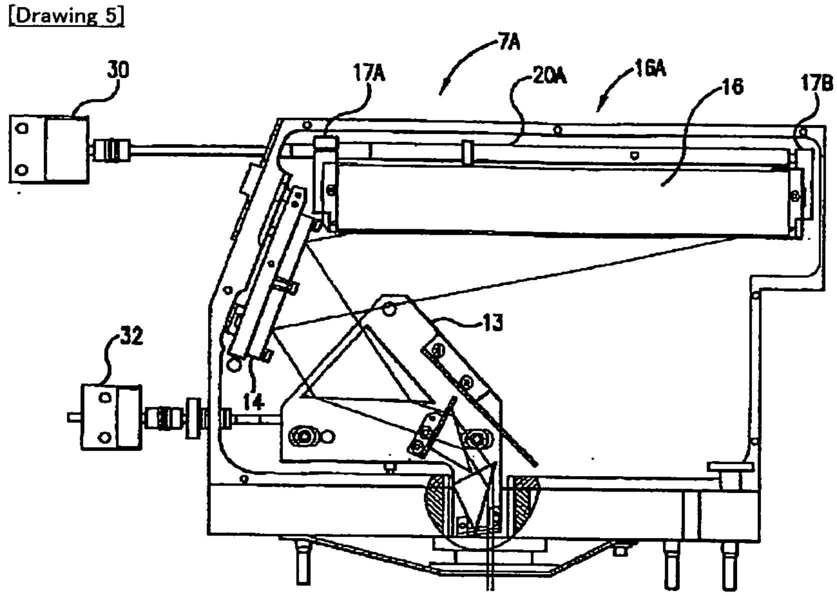
[Drawing 6 D]



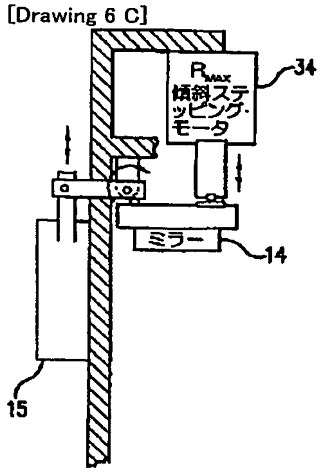
[Drawing 4]



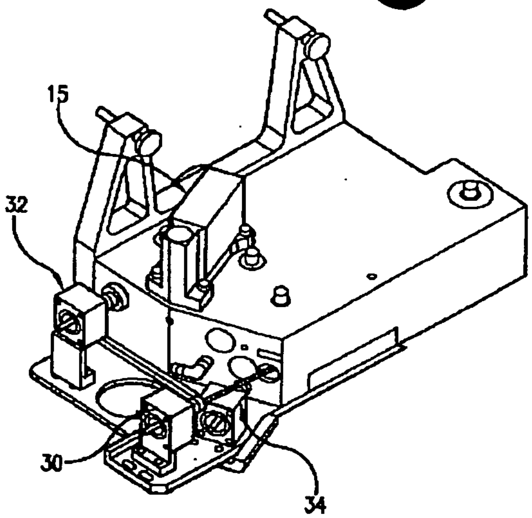
[Drawing 5]



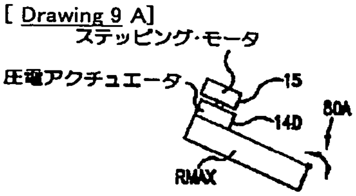
[Drawing 6 C]



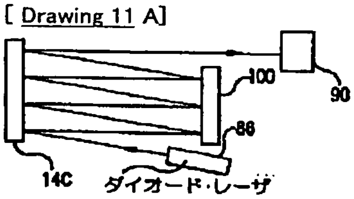
[Drawing 7 B]



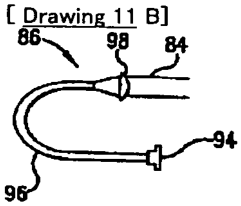
[Drawing 9 A]



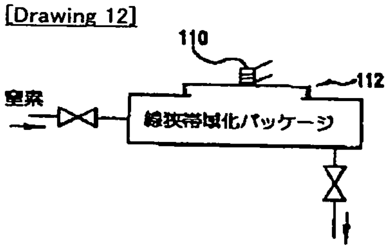
[Drawing 11 A]



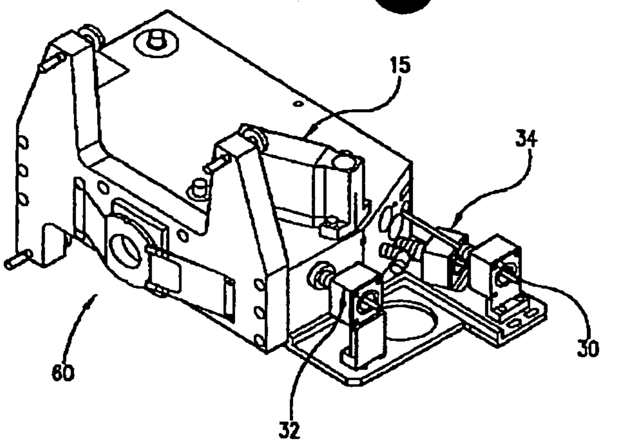
[Drawing 11 B]



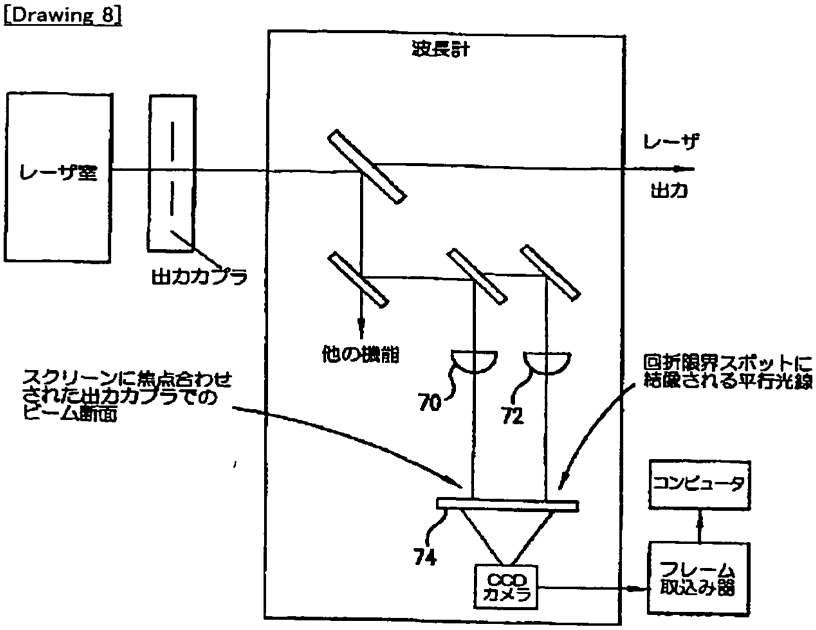
[Drawing 12]



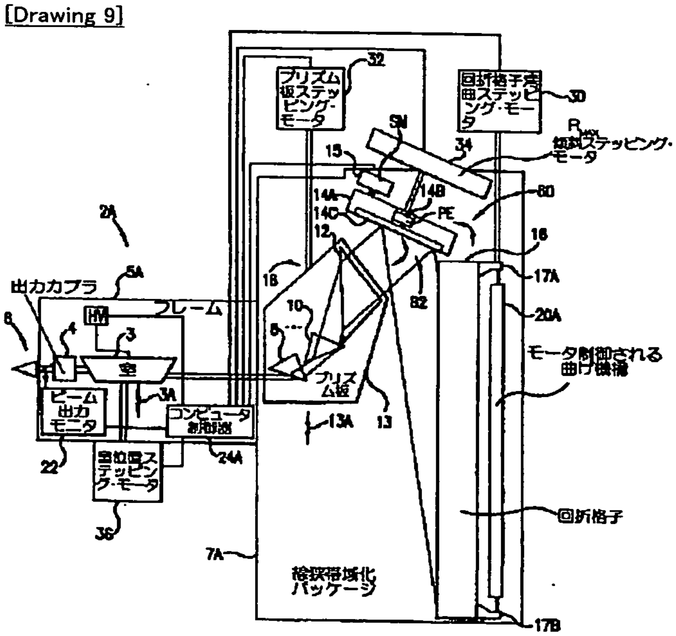
[Drawing 7 A]



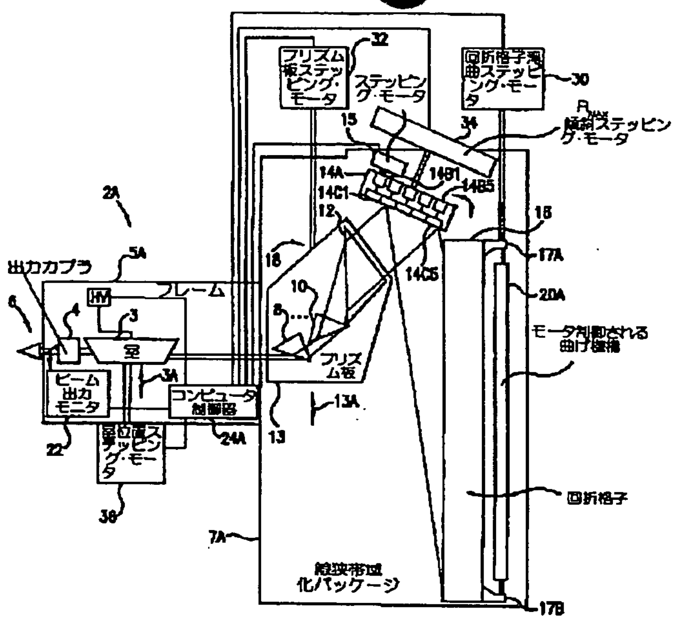
[Drawing 8]



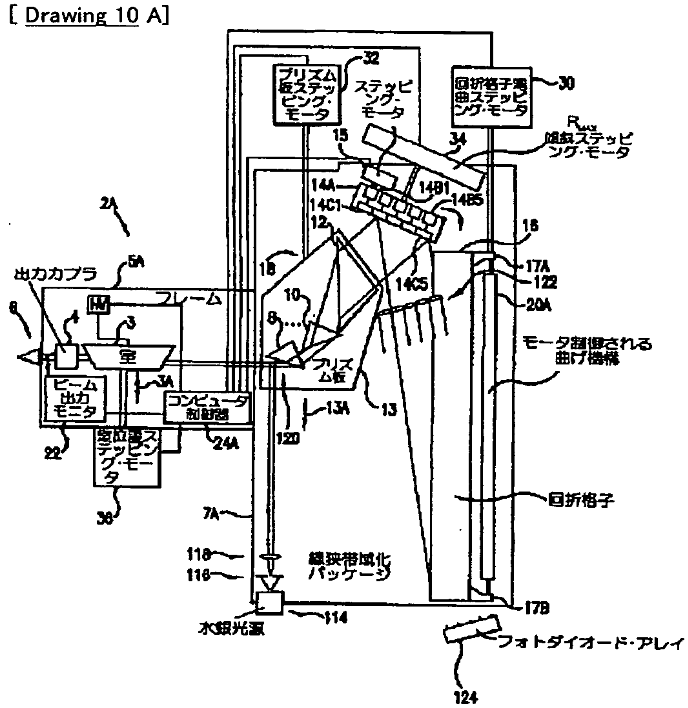
[Drawing 9]



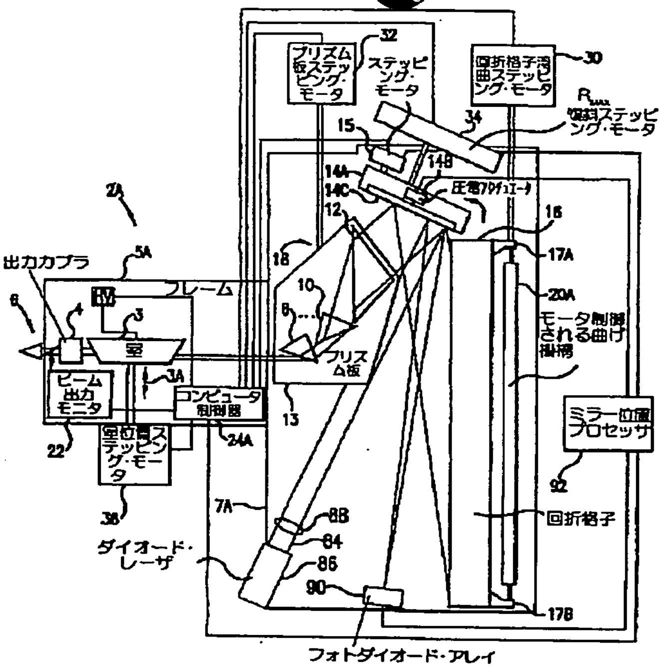
[Drawing 10]



[Drawing 10 A]



[Drawing 11]



[Translation done.]

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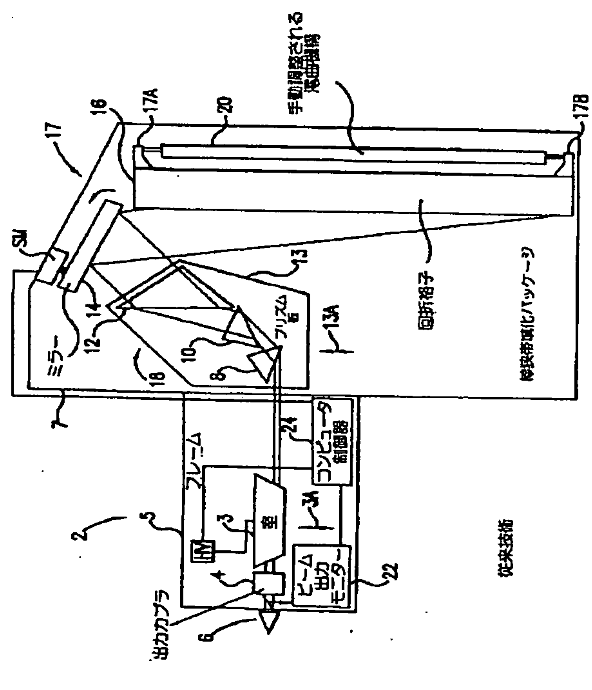
最終頁に続く

(54)【発明の名称】　精密な波長制御を備えた狭帯域レーザ

(57)【要約】　（修正有）
【課題】　レーザに関し、特にビーム品質のフィードバック制御を備えたレーザに関する。
【解決手段】　波長計からのフィードバック信号を用いてパルス・エネルギは、放電電圧を制御することにより、波長は、線狭帯域化モジュールのR_{MAX}ミラーの位置決めによって、また、バンド幅は、線狭帯域化モジュールの回折格子の湾曲を調節することにより制御される。最良の実施形態は、ビーム拡大プリズムが置かれたプリズム板と、R_{MAX}傾斜との自動調節による、水平および垂直ビーム断面の自動フィードバック制御を含み、また別の最良の実施形態は、レーザ室の水平位置を共振空洞内に自動調節することを含む。



【特許請求の範囲】

【請求項１】　Ａ）レーザ・フレームと、
Ｂ）前記フレームに調節自在に取り付けられたレーザ室と、
Ｃ）前記室内に包含されるレーザ・ガスと、
Ｄ）その間のレーザ・ガスと共に利得媒体を定めるような、前記室内に包含され間隔を開けて置かれた２本の延長された電極と、
Ｅ）ビーム拡大器、同調ミラー、及び、回折格子を含む線狭帯域化モジュールと、
Ｆ）前記出力波長を０．１ピコメートル未満の精度で調節する精密な同調手段と、
Ｇ）レーザ出力ビーム波長を検知する波長計と、
Ｈ）コンピュータ制御器と
を含むことを特徴とする、出力レーザ・ビームを発生する狭帯域放電レーザ。

【請求項２】　前記同調手段は、前記同調ミラーを枢転させる少なくとも１つの圧電アクチュエータを含むことを特徴とする請求項１に記載のレーザ。

【請求項３】　前記同調手段は、前記線狭帯域化モジュールのガス圧力を増加または減少する圧力制御手段を含むことを特徴とする請求項１に記載のレーザ。

【請求項４】　前記同調手段は、ステッピング・モータと少なくとも１つの圧電アクチュエータとを含むことを特徴とする請求項１に記載のレーザ。

【請求項５】　前記同調ミラーは、変形自在ミラーであることを特徴とする請求項１に記載のレーザ。

【請求項６】　前記同調ミラーは、複数のミラー・セグメントを含む分割されたミラーであることを特徴とする請求項１に記載のレーザ。

【請求項７】　前記同調ミラーの枢軸位置を検知するミラー位置検知システムを更に含むことを特徴とする請求項１に記載のレーザ。

【請求項８】　前記ミラー位置検知システムは、前記ミラーに向けられた位置検知光源と、前記ミラーからの反射を検知する検知器アレイとを含むことを特徴とする請求項７に記載のレーザ。

【請求項９】　前記光源は、ダイオード・レーザを含むことを特徴とする請求項８に記載のレーザ。

【請求項１０】　前記光源は、水銀ランプを含むことを特徴とする請求項８に記載のレーザ。

【請求項１１】　各々のミラー・セグメントの位置を検知するミラー位置検知システムを更に含むことを特徴とする請求項６に記載のレーザ。

【請求項１２】　前記利得媒体が共振空洞に対して目標とする位置にあるように、前記室を水平方向に位置決めする室位置決め器ユニットを更に含むことを特徴とする請求項１に記載のレーザ。

【請求項１３】　コンピュータ制御器は、前記波長計からのフィードバック情報に基づいて前記室を位置決めするために、前記室位置決め器ユニットを制御するようにプログラムされていることを特徴とする請求項２に記載のスマート・レーザ。

【請求項１４】　前記プリズム・ビーム拡大器は、プリズム板上に配置された複数のプリズムを含み、且つ、前記プリズム板を位置決めするプリズム板位置決め器ユニットを更に含むことを特徴とする請求項１に記載のスマート・レーザ。

【請求項１５】　前記コンピュータ制御器は、前記波長計からのフィードバック情報に基づいて前記プリズム板を位置決めするために、前記プリズム板位置決め器ユニットを制御するようにプログラムされていることを特徴とする請求項４に記載のスマート・レーザ。

【請求項１６】　前記出力レーザ・ビームの垂直空間パラメータを制御するために前記R_{MAX}ミラーを傾斜させる、R_{MAX}傾斜位置決め器を更に含むことを特徴とする請求項１に記載のスマート・レーザ。

【請求項１７】　前記コンピュータ制御器は、前記波長計からのビーム情報に基づいて前記R_{MAX}ミラーを傾斜させるために、前記傾斜位置決め器を制御するようにプログラムされていることを特徴とする請求項６に記載のスマート・レーザ。

【請求項１８】　前記ビーム拡大器は、可動プリズム板上に配置された複数のプリズムを含み、且つ
Ａ）前記コンピュータ制御器からの制御信号に応じて、前記室を水平方向に位置決めする室位置決め器ユニットと、
Ｂ）前記コンピュータ制御器からの制御信号に応じて、前記プリズム板を位置決めするプリズム板位置決めユニットと、
Ｃ）前記コンピュータ制御器からの制御信号に基づいて、前記R_{MAX}ミラーを傾斜させるR_{MAX}傾斜位置決め器と、
Ｄ）前記コンピュータ制御器からの制御信号に基づいて、前記出力ビームの公称波長を調節するために、前記R_{MAX}ミラーを枢転させるR_{MAX}枢軸位置決め器とを更に含むことを特徴とする請求項１に記載のスマート・レーザ。

【請求項１９】　前記回折格子湾曲位置決め器は、ステッピング・モータを含むことを特徴とする請求項１に記載のスマート・レーザ。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、１９９９年９月３日に出願されたシリアル番号０９／３９０，５７９の一部継続出願である。本発明はレーザに関し、特にビーム品質のフィードバック制御を備えたレーザに関する。

【０００２】

【従来の技術】多くのレーザに関する応用例では、ビーム出力の正確な制御が必要である。この種のレーザの応

用例の1つが、集積回路リソグラフィの光源である。現在、 ＫｒＦエキシマレーザは、最新の集積回路リソグラフィ装置において最も選択されている光源である。生産量を増やし、より精密な集積回路パターンを生成する努力がなされているため、光源の仕様はより厳しくなってきている。２４８ナノメートルのＫｒＦレーザの一般的な仕様は、バンド幅が約０．６ピコメートル半値全幅、波長安定度が指定波長の０．１ピコメートル以内、及び、エネルギ線量安定度が約±０．５パーセントを必要とする。さらに、ビームの断面輝度値を制御することが重要である。

【０００３】図1に、集積回路リソグラフィに使用される従来のＫｒＦエキシマレーザ・システムの特徴の一部を示す。このシステムは、利得媒体をその間に持つ２本の延長された電極（図示しない）を含むレーザ室３が内部に取り付けられたレーザ・フレーム構造５、不釣合いに大きく示された線狭帯域化モジュール７（「線狭帯域化パッケージ」またはＬＮＰと呼ぶ）、及び、出力カプラ４を含む。図1のＬＮＰの部分は、ＬＮＰの平面図を表している。ビーム断面は一般的に矩形で、通常、幅約３．５ミリメートル、高さ約１５ミリメートルである。従来の装置では、線狭帯域化モジュール７および出力カプラ・モジュール４（通常、部分反射ミラーを含む）の各々は、レーザ・フレーム構造５に動かないように取り付けられているフレームを含む。出力カプラ・モジュールと線狭帯域化モジュールとのフレーム内の光学部材は、レーザの共振空洞を定めるために手動で調節される。室は、時々図１の矢印３Ａで示すビーム幅の方向に、定められた共振空洞内で手動による精密な位置決めをすることができるように、レーザ・フレーム内に調節自在に取り付けられる。これらの調節によりレーザ技術者は、最適ビーム出力パラメータが達成されるように共振空洞を利得媒体と一直線に並べることができる。例えばこの従来技術の実施形態では、プリズム・ビーム拡大器１８は、プリズム板１３上に取りつけられたプリズム８、１０、及び、１２を含む。従来の装置では、プリズム板１３は、アラインメント技術として矢印１３Ａの方向に手動で調節することができる。従来の装置はまた、曲げ機構２０を拡張または収縮することにより、脚部１７Ａおよび１７Ｂに対してより大きい又は小さい圧縮力を掛け、回折格子１６の表面湾曲をより強めの、又は、より弱めの凹面形状に手動調節することを含む。調節は主として、出力ビームのバンド幅を制御するために行う。回折格子表面に凹面形状を強いる従来技術は、他に米国特許第５，０９５，４９２号に記載されている。

【０００４】現在使用されている従来技術の一般的なリソグラフィ用エキシマレーザは、２つの自動フィードバック制御を組み込み、パルスエネルギと公称波長とを調節する。パルスエネルギは、それを目標とする限界内に調節するために、図1に示すように出力パルスエネルギ

をビーム出力モニタ２２で測定し、次に電極間に加えられる高電圧を制御するために、これらの測定値とコンピュータ制御器２４とを使用することにより、フィードバック・システムにおいて制御される。ビーム出力モニタ２２（波長計とも呼ばれる）は、公称波長およびパルス化された出力ビームのバンド幅も測定する。コンピュータ制御器２４は、ビームの公称波長を目標とする限界内に制御するためにステッピング・モータ１５を使って同調ミラー１４の枢軸位置を調節する。

【０００５】従来の装置では、ステッピング・モータ１５は、１マイクロメートルまでの小さな増分でステップを設定することができる。レバー連係は、これらのステップを２６分の１に縮小し、ステップのサイズを３８ナノメートルに減少させる。これらの線形ステップは、ステッピング・モータの最小の線形ステップの各々がミラー１４に対して約０．４７マイクロラジアンの枢転作用を生み出すように、同調ミラー１５に枢軸線１７に関する枢転運動をもたらす。経験上０．４７マイクロラジアンの枢転は、レーザの公称波長に約０．０５ピコメートルの変化を生じる。

【０００６】

【発明が解決しようとする課題】求められているものは、レーザ・ビーム出力パラメータの、より簡単で速くて正確な制御をもたらす改良である。

【０００７】

【課題を解決するための手段】本発明は、波長計からのフィードバック信号を用いてパルスエネルギ、波長、バンド幅の自動コンピュータ制御を持つスマート・レーザを提供する。パルスエネルギは、放電電圧を制御することにより制御される。波長は、線狭帯域化モジュールのR_{MAX}ミラーの非常に精密で速やかな位置決めによって制御される。バンド幅は、線狭帯域化モジュールの回折格子の湾曲を調節することにより制御される。最良の実施形態は、ビーム拡大プリズムが置かれたプリズム板と、R_{MAX}傾斜との自動調節による、水平および垂直ビーム断面の自動フィードバック制御を含む。また別の最良の実施形態は、レーザ室の水平位置を共振空洞内に自動調節することを含む。最良の実施形態においては、波長モニタからのフィードバック信号は、R_{MAX}ミラーを位置決めするのに使用される。他の最良の実施形態においては、R_{MAX}ミラーからフォトダイオード・アレイ上に反射された別のレーザ・ビームをR_{MAX}ミラーの位置決めに使用する。

【０００８】

【発明の実施の形態】本発明の最良の実施形態は、図面を参照することにより説明される。

（第１の最良の実施形態）本発明の第１の最良の実施形態を表す組合せブロック図の概略を図２に示す。この図は、重要なレーザ・ビーム・パラメータの大幅に改良された瞬時制御を準備するためにレーザ室と部材とのアラ

インメントを自動化するような、従来技術を超える重要な改良を示している。新しいレーザ・フレーム５Ａには、その上に室位置ステッピング・モータが加えられ、室の水平位置を３Ａの方向に自動的に調節する。新しいＬＮＰ７Ａは、プリズム板ステッピング・モータ３２、R_{MAX}傾斜ステッピング・モータ３４、及び、回折格子湾曲モータ３０を含む。これら全てのステッピング・モータは、コンピュータ制御器２４Ａにより制御される。

【０００９】（回折格子表面湾曲の双方向自動制御）回折格子湾曲ステッピング・モータ３０は、回折格子１６の湾曲を制御するために追加される。システムには、新しい曲げ機構設計２０Ａが含まれ、それは、回折格子１６の線引された表面に凹面の湾曲を作るために脚部１７Ａと１７Ｂとを外側に広げる圧縮力、又は、回折格子１６の線引された表面に凸面の湾曲を作るために脚部１７Ａと１７Ｂとを互いに引き寄せる張力を加える能力を持つ。モータ３０の制御は、コンピュータ制御器２４により行なわれる。回折格子曲げ機構の作動に関する基本的部品および機能説明を図３Ａ、３Ｂ、及び、３Ｃに示す。図３Ａは、双方向制御ユニットが取り付けられてはいるが、回折格子に曲げ力が加えられていない回折格子組立体を示す。図示されているのは、回折格子１６、左端板１７Ｂ，右端板１７Ａ，圧縮ばねケース４８、左圧縮ばね５０、右圧縮ばね５１、調節軸４４、及び、調節軸４４にピンで固定されたピストン４９である。調節軸４４は、右端板１７Ａのねじ切り溝と係合するねじ切り長さ４４Ａ（１／４－２８　ＵＮＦ－２Ｂｘ１．３８の長さ）を含む。図３Ａの条件において、両方のばねは、互いを相殺する均等な圧縮力を加えられているか、または両方のばねに負荷が掛けられていない状態である。回折格子表面の湾曲は、軸４４を回転させることによって調節される。軸４４をケース４８内にねじ込むことにより、左圧縮ばね５０は、図３Ｂのケース４８内の２本の矢印で示すようにケース４８の左側とピストン４９とに対して圧縮される。圧縮力は、ロッド４４を右へ、ケース４８を左へと押し、矢印５６で示すように、２枚の端板１７Ａと１７Ｂとが押されて引き離される効果がある。これは、線５８に示すように、回折格子１の表面を凹面形状に曲げる作用がある。

【００１０】これとは逆に、軸４４をケース４８の外に出す方向にねじ込むことで、図３Ｃのケース４８内の２本の矢印で示すように、右圧縮ばね５１は、ケース４８の右側とピストン４９とに対して圧縮される。圧縮力は、ロッド４４を左に、ケース４８を右に引き、矢印５７で示すように、２枚の端板１７Ａと１７Ｂとを引き寄せる効果を持つ。これは、線５９に示すように、回折格子１の表面を凸面形状に変形させる作用がある。この最良の実施形態では、ロッド４４は、１インチにつき２８のねじ切りを持ち、ばねは、１インチにつき定格重量５２ポンドである。オペレータは、この設計により、回折格子表面の湾曲を極めて精密に調節することができる。

【００１１】図４は、出願人および共同出願人が製作した回折格子組立体１６Ａを示す斜視図である。組立体は、回折格子１６、２枚の回折格子端板４２（回折格子１６に接着されている）、右の双方向バンド幅制御端板１７Ａ，止めナット５６、回折格子１６に接着されたインバー床板５３、アラインメント・ロッド４４、ソケット６４、２本の線形軸受６２、圧縮ばねケース４８、右圧縮ばね５１、２本のスラスト軸受６３、ロッド４４にピンで留められたピストン４９、左圧縮ばね５０、ロッド４４にピンで留められた移動限定ピストン５７、ラジアル玉軸受５４、枢軸５５、及び、左のバンド幅制御端板１７Ｂを含む。

【００１２】図５は、ＬＮＰ　７Ａの表面を一部切り取った図である。図は、双方向湾曲制御の回折格子組立体１６Ａを示している。また、図３Ａ、３Ｂ、及び、３Ｃに関連して前述したように、回折格子１６の線引きされた表面の湾曲を凹面から凸面まで制御する、回折格子湾曲制御ステッピング・モータ３０も示す。図５は、プリズム板調節モータ３２も示すが、R_{MAX}ミラー１４のモータ制御は示していない。線狭帯域化パッケージ７Ａの底面図を図７Ａ（正面から、すなわちレーザからＬＮＰに向かって見た図）と図７Ｂ（後面から）とに示す。回折格子湾曲ステッピング・モータ３０がその取付板に取り付けられているのがわかる。プリズム板モータは３２、R_{MAX}傾斜モータは３４、R_{MAX}ステッピング同調モータは１５で各々示されている。本実施形態におけるR_{MAX}ステッピング同調機構は、従来技術の項で記述した従来の機構と実質的に同一のものである。レバー機構は、線形ステッピング・ドライバを２６分の１に縮小し、０．０３８ミクロンの最小ステップを準備する。ＬＮＰに対するビームの出入ポートは６０で示されている。

【００１３】（プリズム板の位置制御）プリズム板１３の位置制御は、プリズム板ステッピング・モータ３２も示している切断図５Ａに描かれている。ステッピング・モータ３２もまた、その取付板に取り付けられて図７Ａと図７Ｂとに示されている。モータ３２の制御は、コンピュータ制御器２４によって行われる。

【００１４】（自動R_{MAX}傾斜制御）R_{MAX}傾斜制御ステッピング・モータは、図７Ａ、図７Ｂ、図６Ａ、図６Ｃ、及び、図６Ｄにおいて３４で示されている。R_{MAX}ミラー１４の傾斜は、これもコンピュータ制御器２４によって制御されるR_{MAX}ステッピング・モータ３４により準備される。ミラー１４の傾斜は、共振空洞内で反射する光の垂直角度を決める。

【００１５】（同調ミラーによる波長選択）この最良の実施形態において、波長の選択は、ステッピング・モータ１５により準備され、本明細書の従来技術の項に記載した従来技術による波長計２２からのフィードバック波

長情報を利用するコンピュータ制御器２４からの指令に基づき、同調ミラー１４の枢軸の水平位置を設定する。

【００１６】（自動室位置制御）この第１の最良の実施形態は、レーザ室３の水平位置（すなわち、レーザ室に包含されている利得媒体の水平位置）を、フレーム５（そこに出力カプラ４と線狭帯域化パッケージ7とが取りつけられている）に関して、ビーム６と垂直の方向に自動的に調節するような、図２に示す室位置ステッピング・モータ３６を含む。

【００１７】（制御）図２に示すコンピュータ制御器２４Ａは、波長計２２からのフィードバック信号に基づいてビーム・パラメータを目標とする範囲内に維持するために、モータ１５に加えてモータ３６、３２、３４、及び、３０を制御する制御アルゴリズムによりプログラムされることが好ましい。簡単な方法は、１箇所（例えば室位置ステッピング・モータ）を除くすべての位置を一定に保ち、パルスエネルギ出力、パルスエネルギ安定度、バンド幅などのパラメータを見て最適なビーム性能を生み出す位置を求めるために、その項目を所定の範囲に亘って走査することである。コンピュータは、これらの走査をオペレータの指示か、または所定の一定間隔で行うようにプログラムすることができる。もし波長計がビーム品質に何らかの低下を検知すれば、最適な位置を求めてコンピュータは、１つまたはそれ以上のこの種の走査を行うようにプログラムすることも可能である。

【００１８】また、レーザのバースト・モード操作の間（例えば、毎秒１０００パルスの割合で３００パルス、続いて０．３秒の休止時間というパルスのバーストを発生するようにレーザが操作されている場合）、ビームパラメータは、パルス数（すなわちバーストの開始からの時間）の関数として変化することが知られている。これらの変化を和らげる、または補償するために、コンピュータ制御器は、１つまたはそれ以上のステッピング・モータをバースト開始からの時間の関数として調節するようにプログラムすることができる。

【００１９】（特定の最適化技術）１つの最良の性能最適化技術では、最適なレーザ性能を判断するために、メリット数Ｍを定義する。次いでメリット数を最大にするための調節を行う。この値は、実時間でビームを測定するセンサからの入力を用いて計算される。これらのセンサは通常、エネルギ安定度、レーザー効率（入力電圧に対する出力エネルギ）、バンド幅、ビーム幅、ビーム対称度、位置決めグ安定度などの値を与える。最も良いメリット数は一般に、リソグラフィ照射などへの適用の際、成功のカギになる最も重要なパラメータをいくつか組み合わせたものになるであろう。例えば、パルスエネルギ／充電電圧（Ｅ）によって測定されるレーザ効率だけが重要だと考えられた場合、メリット数は、

Ｍ＝パルスエネルギ／充電電圧、またはＭ＝Ｅ

になるであろう。

【００２０】もし空間対称性（水平方向）ＳＨがＥに加えて判断される場合は、ＳＨが測定され、重み係数W_{SH}が与えられなければならない。完璧に対称な場合はゼロになる。従ってメリット数に対する新たな公式は次のようになる。

$$M = E - (W_{SH})(SH)$$

次に、Ｍを最小にする調節が行われる。同様に、メリット数Ｍは、垂直対称性（ＶＳ）、バンド幅（Ｂ）、波長の安定度（ＷＳ）、線量の安定度（ＤＳ）など、他のパラメータの関数として得ることもできる。この場合、Ｍの公式は次のようになる。

$$M = E - (W_{SH})(SH) - (W_{SV})(SV) - (W_B)(B) - (W_{WS})(WS) - (W_{DS})(DS)$$

ここでもまた、コンピュータは、最小のメリット数Ｍを達成するために、ステッピング・モータ位置の調節を行い、Ｅ、ＳＨ、ＳＶ、Ｂ、ＷＳ、及び、ＤＳを測定し、重み係数を適用するようにプログラムされる。

【００２１】前述したいくつかの種類のパラメータを考慮したレーザ性能を最適化する技術は多く知られている。１つの最良の実施形態は、で、これはケンブリッジ大学出版局１９９０年発行のW. H.プレス他著「数値解析の手法と科学計算の技術」で記述され、そこで引用されている。簡単に言うと、初期設定のグループが調節のために選択される。調節されるパラメータの数より１つ多い数の構成（１つの構成は調節用の一組の値である）があるであろう。１回の反復に対して各構成に調節が設定され、メリット数が測定される。最悪のメリットの構成はそこで拒絶され、最適の構成に近い新たな構成に入れ替えられる。反復が続行されると、構成のどれでも最適なものとして選択できるまでに構成は互いに近づいてくる。以前の仕事で出願人は、約１０回の反復が最適を見つけるのに十分であることを発見している。下勾配単体法は信頼できる技術であるが、とても急速な収束が必要であれば、他のよく知られた技術を利用することもできる。

【００２２】（追加のビーム・パラメータの測定）従来技術の項で述べたように、従来技術のリソグラフィ・レーザは、パルスエネルギ波長とバンド幅とを高速で測定する波長計と共に準備された。パラメータは通常、１０００ヘルツから２０００ヘルツの繰返数のレーザ・パルスの各々について測定される。本出願人は、様々なビーム・パラメータを測定するために図８に示すような光学的配列を準備した。出力カプラ開口でのレーザ・ビームの画像は、レンズ７０を通して蛍光スクリーンに光学的に中継され、垂直および水平対称性を含むビーム・パラメータは、図８に示すように、蛍光スクリーン７４上に焦点合わせしたＣＣＤカメラを利用して測定される。蛍光スクリーンは、レーザからの紫外線光を、ＣＣＤカメラにより監視される可視光に変換する。カメラからのアナログ出力は、ビデオフレーム取込み器でデジタルに変

換され、フレーム取込み器の出力は、コンピュータ・プロセッサによって解析される。

【００２３】前記仕事に関連して本出願人は、図８に示すようにレンズ７２を通る第２のビーム経路を用いて、ビーム発散、ビーム位置合わせ、及び、ビーム位置合わせ安定度を監視することもできた。この場合、レンズ７２は、レーザ・ビームの焦点を蛍光スクリーン７４上に合わせ、レンズに入射する完全に平行な光が蛍光スクリーンで回折限界スポットとして現れるように位置される。従ってスポットの大きさは、ビーム発散の尺度であり、スポットの動きは、ビーム位置合わせの変化の尺度である。これらのパラメータを考慮してレーザ性能を最適化するために、これらの追加パラメータは、本発明において用いることができる。

【００２４】（波長の制御）レーザ・リソグラフィにおいて波長を制御する一般的な方法は、レーザのオペレータが波長を特定し、その特定した波長をフィードバック・プログラムにより自動的に作り出せるようなレーザ制御システムを構築することである。これは通常好ましく、なぜなら集積回路を生産する時にレーザは、１秒の数分の１から数秒というバースト間の休止を含み、毎秒１０００パルスの繰返数で１００パルスという短いパルスのバーストで通常は操作されるからであり、その結果、ビームの波長は、利得媒体およびレーザ・システム用光学部品の変更により変動するからである。

【００２５】図１に示す従来技術のリソグラフィ・レーザ・システムでは、レーザ出力ビームの波長は、出力モニタ２２で監視される一方、回折格子およびエタロンを組合わせた波長モニタは、約０．１ピコメートルの精度で波長を監視する。モニタは、公知の吸収線に対して周期的に較正される。この種の従来の波長計は、アメリカ特許第５，９７８，３３４号の中に記載されており、参照文献として本件に取り入れられている。例えばレーザのオペレータは、レーザ波長を２４８，３２１．３０ピコメートルに制御するようにコンピュータ制御器２４をプログラムすることができる。制御器２４は、モニタ２２から波長の測定値を受取り、その情報を用いてモニタ２２により測定された波長を目標とする波長２４８，３２１．３０ピコメートルに維持するために波長が増加または減少するように、ステッピング・モータ１５を調節してミラー１４を枢転させる。この従来のステッピング・モータ１５の動きの最も小さい増分で、出力波長は約０．０５ピコメートル変化する。

【００２６】（より精密な波長制御）より精密な波長制御を準備する最良の実施形態を図９に示す。この実施形態では、従来のステッピング・モータ１５は、回転運動の１度だけ同調ミラー１４Ｃを枢転させる（８２で示す垂直枢軸線に関して）ために構成された、圧電アクチュエータ１４Ｂを内部に含むミラー機構１４ａを枢転させる（８０で示す垂直枢軸線に関して）ために用いられる。ミラー１４Ｃの寸法は、約１．５インチｘ３．０インチで、厚さは約２．５インチである。また重さは約２オンスである。小さな圧電アクチュエータは、このサイズのミラー用にフィジク・インストルメントなどの供給元から市販されており、５０００ヘルツの繰返数において０．１ラジアンの枢転範囲を極めて精密な精度で準備できる。これらの同調ミラーシステムは、高電圧信号を圧電モータに供給する電子駆動ユニットを備えている。

【００２７】この最良の実施形態では、コンピュータ制御器２４Ａは、ステッピング・モータ１５と圧電ユニット１４Ｂとの両方を制御するようプログラムされている。圧電アクチュエータ１４Ｂは、レーザを波長計の持つ約０．１ピコメートルの精度よりもずっと高い精度で同調できるように、ミラー１４Ｃを極めて精密な精度で回転させることができる。図９Ａに示す他の配置において、圧電アクチュエータ１４Ｄは、ステッピング・モータ１５と直列に取り付けられ、圧電駆動の線形膨張および収縮を作用させて、R_{MAX}ミラーを枢軸線８０Ａに関して枢転させる。

【００２８】（予備同調）従来の波長同調配置における問題の１つは、フィードバック・システムであり、それはレーザ制御が、目標とする波長を発生させるために必要な調節をできるまでに、いくつかのパルスを必要とするからである。図１１は、レーザ操作に先だって同調を行うために特に設計された実施形態を示す。ダイオード・レーザ・システム８６からの平行ビーム８４は、ミラー１４Ｃから反射され、円筒形レンズ８８によって、ミラー１４Ｃの枢軸位置を測定するために使用されるフォトダイオード・アレイ９０上の細い線に焦点合わせされる。ＰＤＡ９０からの情報は、フィードバック構成においてミラー位置決めプロセッサ９２が使用し、コンピュータ制御器２４Ａから命令されるミラーの枢転角度を発生させるために、ステッピング・モータ１５および圧電アクチュエータ１４Ｂの位置を制御する。コンピュータ制御器２４Ａは、目標とする波長出力を発生するために予め適切なミラー位置を要求できるように、ＰＤＡ出力データと波長との相関マトリックスを確立するようにプログラムされる。

【００２９】平行ビーム８４は、コア径約２．５ミクロンの単一モード・ファイバ９６に連結し、６７０ナノメートルで作動するダイオード・レーザ９４を含むダイオード・レーザ・システム８６により準備することができる。ファイバ９６から出た光は、非球面レンズ９８により平行ビーム８４に整えられる。レンズ９８の焦点距離は約２０ミリメートルで、そのために直径約５ミリメートルのビーム８４をもたらす。このビームの発散は、おおよそ次式により表される。

$$\theta = 1.22 \frac{\lambda}{D}$$

ここで、λは波長６７０ナノメートル、Ｄはビーム径５ミリメートルであり、従って発散は、約θ＝１．６３ｘ１０$^{-4}$ラジアンである。この低発散ビームは、レンズ８８によりダイオード・アレイ９０上に約５００ミリメートルの距離で焦点合わせされる。ＰＤＡにおけるスポットサイズは、約８２ミクロンである。最良のＰＤＡは、１４ミクロンの間隔で２０４８のピクセルを持つ。従ってスポットは、約６ピクセルを網羅する。レーザのオペレータは、レーザーを±０．１ピコメートルまたはそれ以上の精度で目標とする波長に制御することを望む。ＫｒＦレーザの波長の変化１ピコメートルは、ミラー１４の枢転自在な位置の変化約９．９マイクロラジアンに相当する。

【００３０】ミラー１４とＰＤＡ９０との間の距離は、約３００ミリメートルである。ミラー１４の９．９マイクロラジアンの傾斜は、ＰＤＡ９０上のビームスポットの５．９４ミクロンのずれを生じる。スポットの厚さは約８２ミクロンである。０．６ミクロンのずれ（０．１ピコメートルの波長のずれに相当する）の精度を達成しようとすると、ビームスポットの急勾配な部分（スポットの半値部分の近くの）に沿ってピクセルの輝度を監視する必要がある。プロセッサ９２は、これを行うようにプログラムされることが好ましい。各ピクセルは、市販の安価なＰＤＡアレイに対して２５６レベルの輝度応答を持つ。スポットの急勾配な部分のいくつかのピクセルを平均することによっても精度を向上することができ、多くの輝度を利用できる時間間隔に亘って平均することによって、更に向上させることができる。別の最良の方法を図１１Ａに示す。ここでは中間固定ミラー１００は、ビームをミラー１４Ｃから４回反射させ、それによりピコメートルの波長に対してずれを４倍し、２４ミクロンのずれを生じる。従って０．１ピコメートルの変動は、２．４ミクロンのビームスポットのずれに対応し、これによりスポットの急勾配エッジのピクセル輝度の変化を見ることは、はるかに楽になる。

【００３１】（チャープ）波長の時間的変化は、当業者の間で「チャープ」または「波長のチャープ」と呼ばれている。これらの変化は、０．００１秒またはそれ以下といった時間スケールで非常に急速に起こる。上述のように、チャープは、室内や光学部材の熱効果や音響効果など、多くの要因によって起こり得る。ほとんどの場合チャープは歓迎されず、本発明が提供する波長の高速制御は、チャープを最小に押さえるのに利用することができる。さらに、ある制御されたチャープが必要とされる状況があり、その時チャープは、コンピュータ制御器２４Ａおよびプロセッサ９２を使用するためにプログラムされる。図１１、図１１Ａ、及び、図１１Ｂに示すシステムの主な利点は、レーザ操作に先立ち、過去の較正データに基づいてミラー位置を設定できることである。

【００３２】パルス繰返数１０００ヘルツから５０００ヘルツで作動しているガス放電レーザにおいては、約３キロワットが少量のレーザガス内に周期的に放出されている電極の間を、レーザガスが最大毎秒１００メートルの速度で循環しており、プリズムや他の光学部材は、ゼロワットから約５０ワットまで変動する平均エネルギを持つ紫外線光パルスに曝らされていることを理解する必要がある。従って、熱的および他の効果は、波長のごくわずかな変化を生じることができ、オペレータは、０．１ピコメートルまたはそれ以下の精度でそれを制御しようと試みることが可能である。図１１に示す実施形態は、これらの効果により生じた波長の歪みを補償するために、オペレータが同調ミラー１４６を調節することを可能にする。レーザ操作の特定モードに対応して必要のないチャープ模様が検知された場合、コンピュータプロセッサ２４Ａおよび９２は、チャープを最小にするために同調ミラー１４Ｃを前もって制御するようにプログラムすることができる。

【００３３】（変形自在ミラー）図１０は、本発明の別の最良の実施形態を示す。この場合の実施形態は、図９および図１１に示すものとほぼ同様であるが、図９および図１１の実施形態のミラー１４Ｃが５つのセグメント１４Ｃ１、２、３、４、及び、５に分割されてい点で異なる。各セグメントは、それ自身の圧電ドライバで制御される。圧電部材は、ミラーを目標とする角度に向かせるため、また、ミラーが位相に関してオフセットした場合にオフセットが波長の倍数であるために、傾斜部、先端部、及び、ピストンを準備することが好ましい。この種の分割ミラーは、１９９０年７月３１日発行の米国特許第４，９４４，５８０号の中に記載されており、参照文献として本件に取り入れられている。分割された個々のミラーはずっと軽量なので、はるかに高速な制御が可能である。現在の圧電技術は、最大１０，０００ヘルツの繰返数での枢転自在な調節を可能にする。

【００３４】これらのミラーの位置は、図１０Ａに示すように、レンズ１１８により平行にされ、レーザ・ビームの上方に位置するミラー１２０から反射された、スリット１１６を通過するランプ１１４からの水銀光源を使って監視することができる。水銀ビームは、ビーム拡大プリズム８、１０，及び、１２を通って拡大され、ミラーアレイ１２２によりPDAアレイ１２４上に焦点合わせされる。図１０に示す型の圧電駆動の変形自在ミラーは、カリフォルニア州サンディエゴ所在のサーモトレックス・コーポレーションなど多くの供給元から入手可能である。

【００３５】（圧力変調）波長の非常に精密な同調を準備する別の方法は、LNP内のガス圧を制御することである。LNPは窒素で浄化することが好ましい。過去において窒素圧力は、大気圧をごくわずか上回る圧力で一定に保たれてきた。窒素圧力の変化は、屈折率を変化させ、それにより回折格子上の入射角をごくわずか変化させ

る。パージガスの流れはLNPを通る連続した流れなので、入口浄化ラインまたは出口浄化ラインの制御バルブを使って圧力を変えることができる。それに対する応答は、比較的ゆっくりである。圧力の急速な変化は、比例ソレノイド・アクチュエータ１１０とベローズ１１２とを利用して図１２に示すように準備することができる。また、ヘリウムなど他のパージガスも窒素の代わりに用いることができる。

【００３６】本発明は、特定の実施形態を参照して開示および説明されてきたが、関連する原理は、数多くの他の実施形態にも利用し易いことが、当業者には明らかである。例えば各ステッピング・モータは、交流または直流モータ、又は、油圧または空気位置決め装置などの代替位置決めユニットと交換できる。提案されたコンピュータ・プログラム以外の位置決め装置を制御する多くの方法も利用することができる。１つまたはそれ以上のステッピング・モータを出力カプラに適用し、R_{MAX}ミラーについての上記説明と同様な技術を用いて、出力カプラを自動的に位置決めすることができる。３つの強い永久磁石は、図６に示すように、１つはピストンと入れ換え、残りは２つの圧縮ばねの代わりとして用いることができる。磁石６０はロッド４に固定され、磁石６２および６４はケース８に固定される。ロッド４は、磁石６２および６４の孔を通過する。ロッド４をケース８の中に、及び、ケースから外にねじ込む効果は、前述の効果と実質的に同じである。回折格子の湾曲は、多くの技術のどれを使用しても達成することができる。例えば多くの点に圧縮または張力を加えて目標とする事実上いかなる形をも作り出し、これらの形をフィードバック・コンピュータ制御にかけることができる。ミラー１４は、平滑変形自在ミラーなど他の型の変形自在ミラーであってもよいし、ビーム拡大は、全反射ビーム拡大型であってもよい。従って本発明は、別記請求範囲およびそれらの法的同等範囲で示される範囲においてのみ限定される。

【図面の簡単な説明】

【図１】従来の狭帯域レーザの構成を示す図である。

【図２】本発明の最良の実施形態を示す図である。

【図３Ａ】回折格子曲げ機構の作動原理を示す図である。

【図３Ｂ】回折格子曲げ機構の作動原理を示す図である。

【図３Ｃ】回折格子曲げ機構の作動原理を示す図である。

【図４】曲げ機構の予想図である。

【図５】図２の最良の実施形態のいくつかの特徴を示す図である。

【図６Ａ】図２の実施形態の他の特徴を示す図である。

【図６Ｂ】図２の実施形態の他の特徴を示す図である。

【図６Ｃ】図２の実施形態の他の特徴を示す図である。

【図６Ｄ】図２の実施形態の他の特徴を示す図である。

【図７Ａ】図２の実施形態における線狭帯域化モジュールの底部予想図である。

【図７Ｂ】図２の実施形態における線狭帯域化モジュールの底部予想図である。

【図８】選択されたビーム・パラメータを測定するための光学的配列を示す図である。

【図９】最良の実施形態の特徴を示す図である。

【図９Ａ】最良の実施形態の特徴を示す図である。

【図１０】分割されたR_{MAX}を持つ実施形態を示す図である。

【図１０Ａ】図１０の実施形態と同様な実施形態を示す図である。

【図１１】他の最良の実施形態の特徴を示す図である。

【図１１Ａ】他の最良の実施形態の特徴を示す図である。

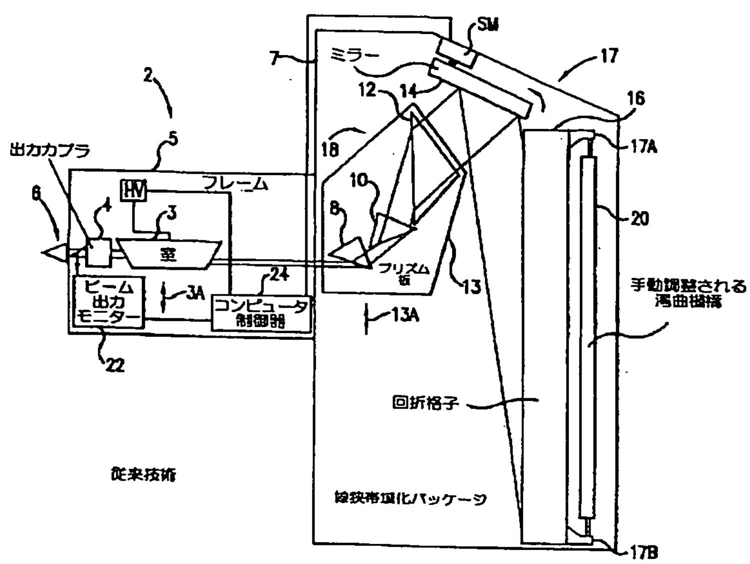
【図１１Ｂ】他の最良の実施形態の特徴を示す図である。

【図１２】圧力制御されたＬＮＰを示す図である。

【符号の説明】

３　レーザ室
３Ａ　ビーム幅の方向
４　出力カプラ
５　レーザフレーム構造
６　ビーム
７　線狭帯域化モジュール
８　プリズム
１０　プリズム
１２　プリズム
１３　プリズム板
１３Ａ　プリズム板の調節方向
１４　同調ミラー
１５　ステッピング・モータ
１６　回折格子
１７　枢軸線
１７Ａ　脚部
１７Ｂ　脚部
１８　プリズム・ビーム拡大器
２０　曲げ機構
２２　ビーム出力モニター
２４　コンピュータ制御器

【図１】



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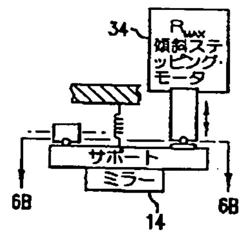

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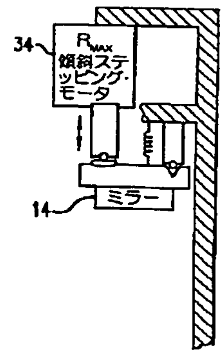

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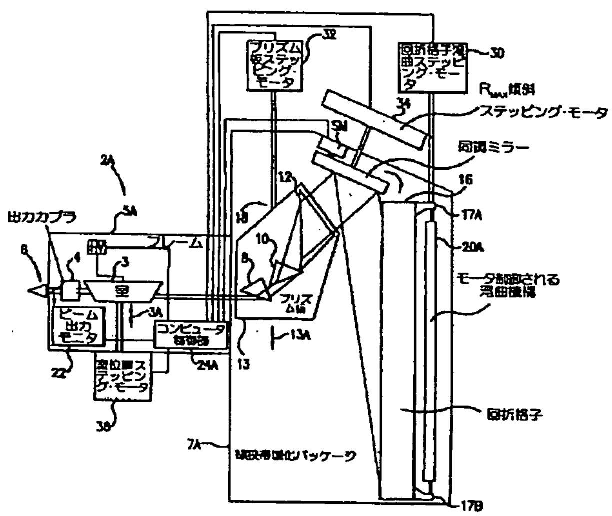

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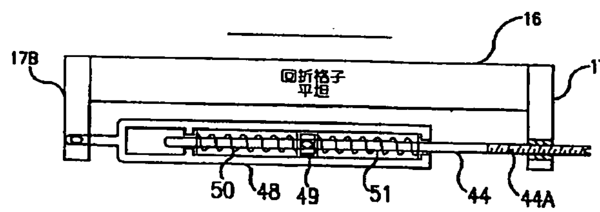

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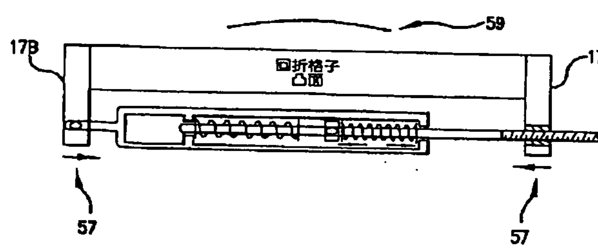

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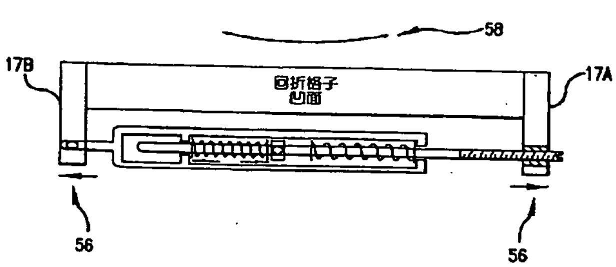

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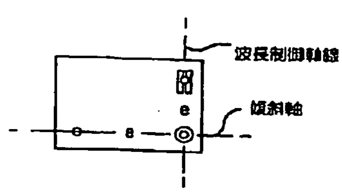

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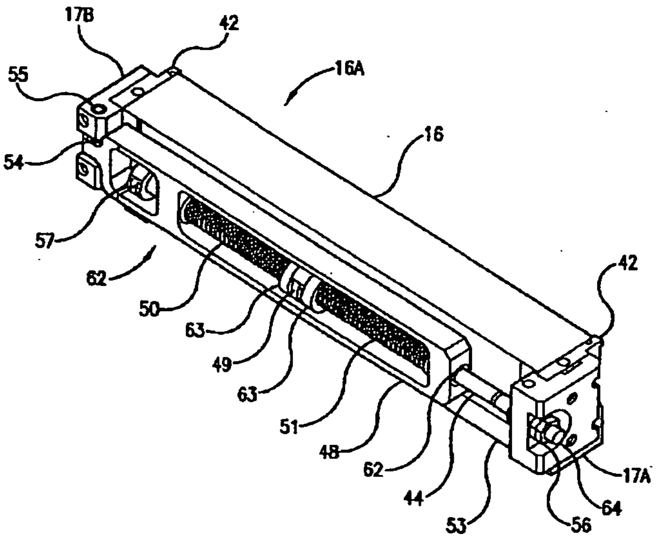

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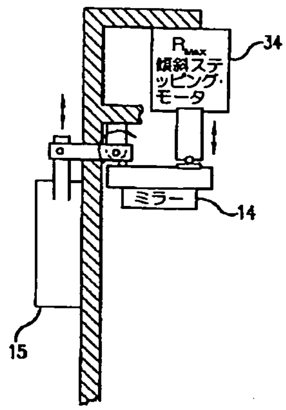

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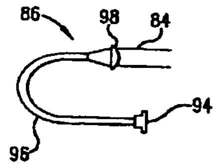

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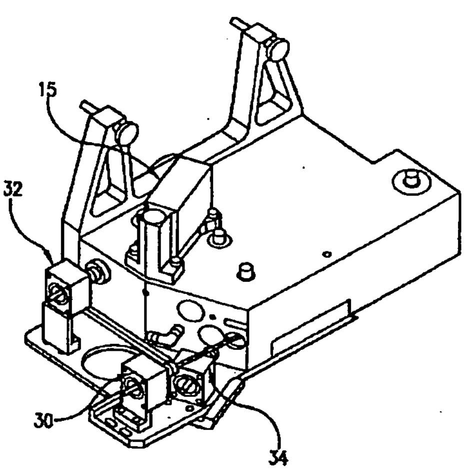

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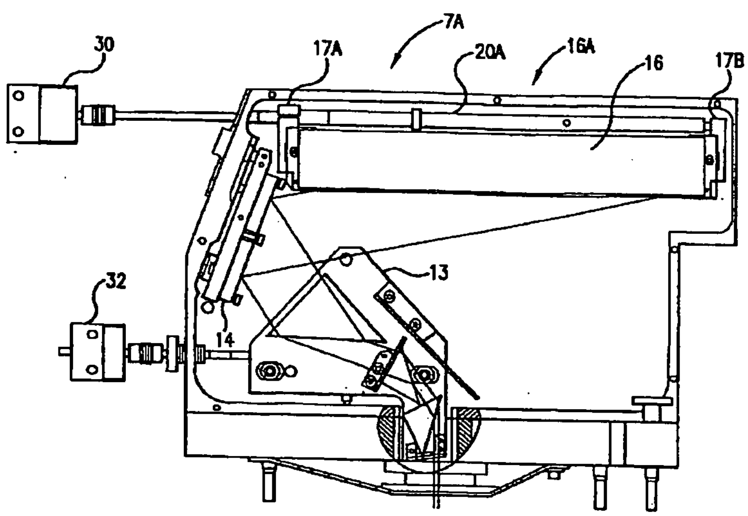

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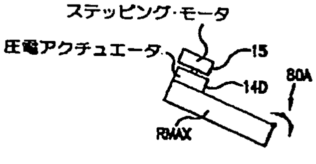

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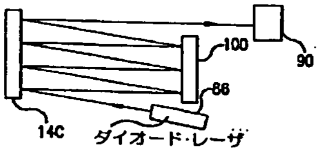

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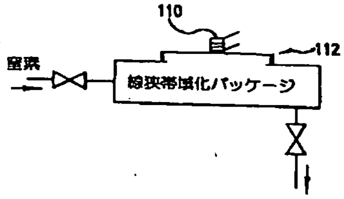

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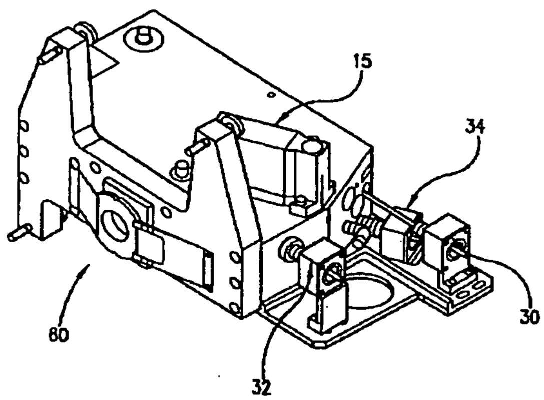
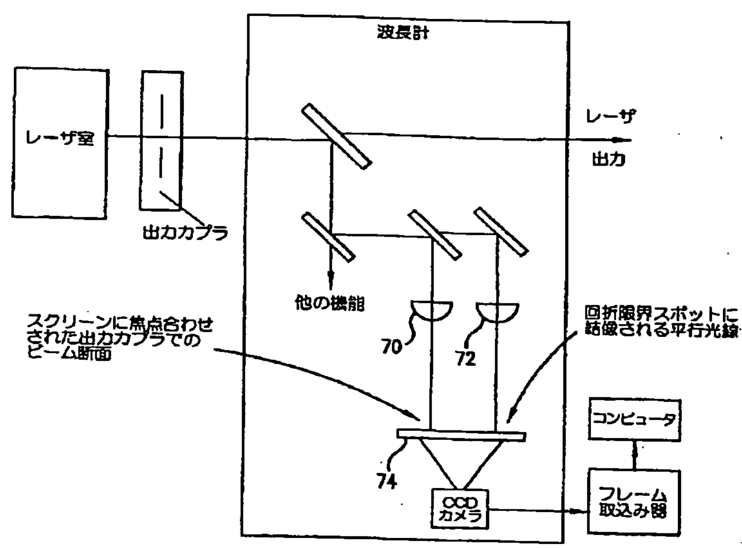
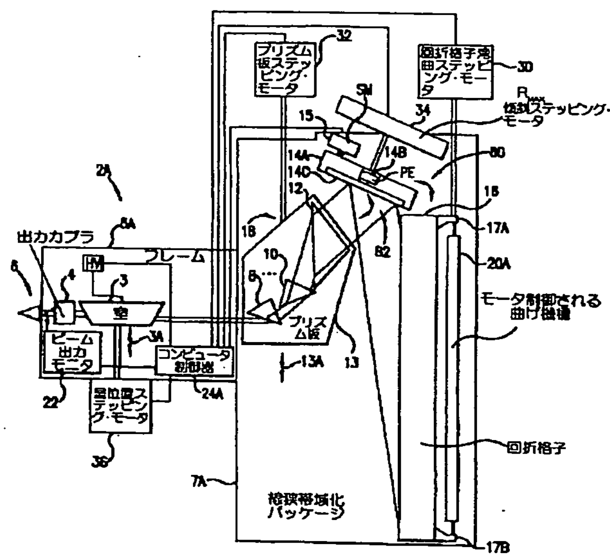

15
34
30
32
60

【図８】


波長計
レーザ室
出力カプラ
レーザ
出力
他の機能
70
72
スクリーンに焦点合わせされた出力カプラでのビーム断面
回折限界スポットに結像される平行光線
74
コンピュータ
フレーム取込み器
CCDカメラ

【図９】



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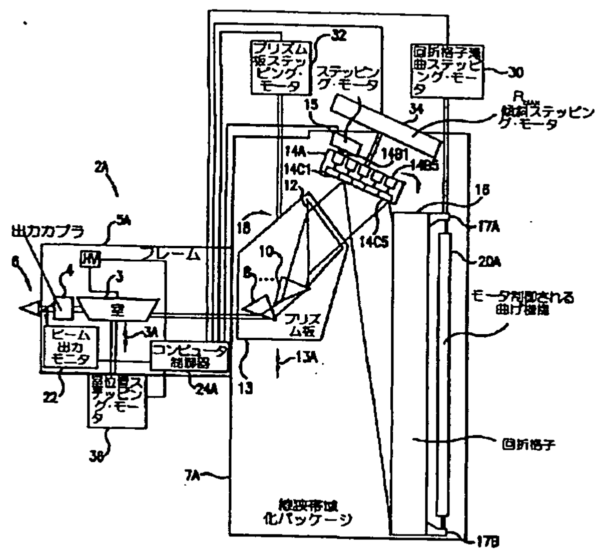

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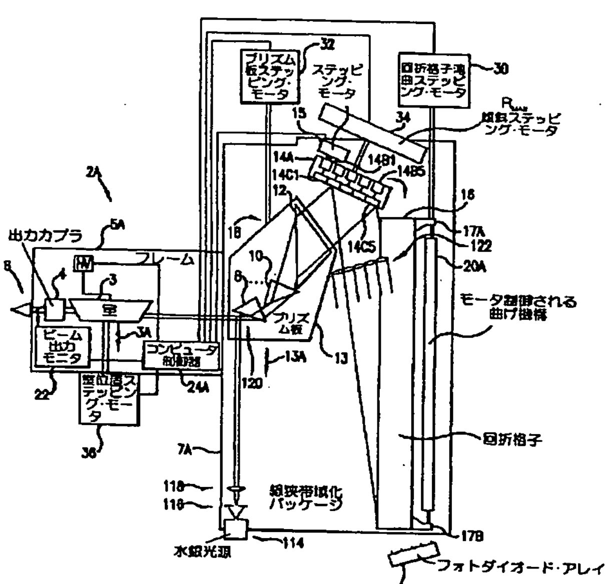

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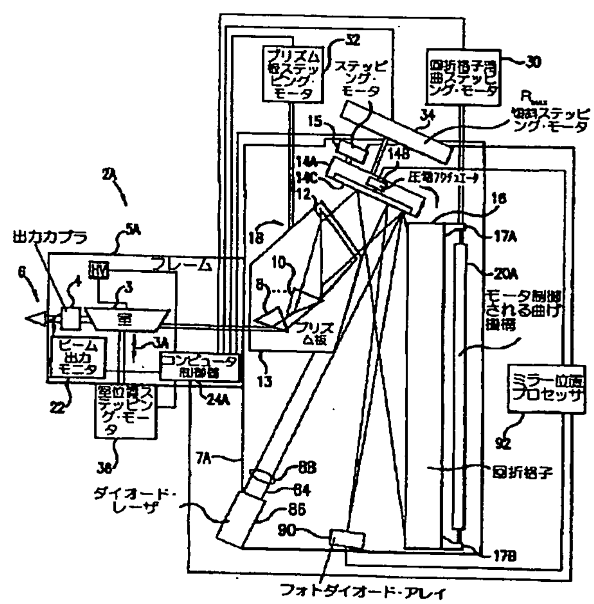

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【外国語明細書】

NARROW BAND LASER WITH FINE WAVELENGTH CONTROL

This is a continuation-in-part application of Serial No. 09/390,579; filed September 3, 1999. This invention relates to lasers and in particular to lasers with feedback control of beam quality.

BACKGROUND OF THE INVENTION

In many laser applications precise control of beam output is desired. One such application for such lasers is the light source for integrated circuit lithography. Currently the KrF excimer laser is the choice light source for state of the art integrated circuit lithography devices. Specifications for the light source are becoming tighter as efforts are made to increase production and produce finer integrated circuit patterns.

Typical specifications for a 248 nm KrF laser call for bandwidths of about 0.6 pm full width half maximum, wavelength stability within 0.1 pm of the specified wavelength and energy dose stability of about ± 0.5 percent. In addition, control of beam cross section intensity values are important.

FIG. 1 shows some of the features of a prior art KrF excimer laser system used for IC lithography. The system includes a laser frame structure 5 within which is mounted a laser chamber 3 containing two elongated electrodes (not shown) between which is a gain medium, a line narrowing module (referred to as a "line narrowing package" or LNP) 7 shown disproportionately large and an output coupler 4. The LNP portion of FIG. 1 represents a top view of the LNP. The beam cross section is generally rectangular, typically about 3.5 mm wide and about 15 mm high. In prior art devices each of the line narrowing module 7 and the output coupler module 4 (typically comprising a partially reflecting mirror) comprise frames which are fixedly mounted to laser frame structure 5. Optical

components within the frames of the output coupler module and the line narrowing module are adjusted manually to define the laser resonance cavity. The chamber is adjustably mounted within the laser frame so that it can be finely positioned manually within the defined resonance cavity from time to time in the direction of the beam width as shown by arrows 3A on FIG. 1. These adjustments permit a laser technician to align the resonance cavity with the gain medium in order to achieve optimum beam output parameters. In this prior art embodimet, for example, a prism beam expander 18 is comprised of prisms 8, 10 and 12 mounted on prism plate 13. In the prior art device, prism plate 13 can be manually adjusted in the direction of arrows 13A as an alignment technique. The prior art device also includes a manual adjustment of the curvature of the surface of grating 16 into an increasingly or decreasingly concave shape by expanding or contracting bending mechanism 20 to place larger or smaller compressive forces on legs 17A and 17B. The adjustment is done primarily to control bandwidth of the output beam. Another prior art technique for forcing a concave shape on the grating surface is described in U.S. Patent No. 5,095,492.

Typical prior art lithography excimer lasers now in use incorporate two automatic feedback controls to regulate pulse energy and nominal wavelength. Pulse energy is controlled in a feedback system by measuring the output pulse energy with a beam output monitor 22 as shown in FIG. 1 and then using these measurements with a computer controller 24 to control the high voltage applied between the electrodes in order to regulate pulse energy within desired limits. The beam output monitor 22 (also called a wavemeter) also measures the nominal wavelength and bandwidth of the pulsed output beam. Computer controller 24 adjusts the pivot position of tuning mirror 14 using stepper motor 15 in order to control the nominal wavelength of the beam to within desired limits.

In prior art devices stepper motor 15 can be stepped in increments as small as 1 μm. A lever linkage de-magnifies these steps by a factor of 26 to reduce the size

of the step to 38 nm. These linear steps provide pivot movement to tuning mirror 15 about pivot line 17 so that each minimum linear step of stepper motor produces a pivot action of mirror 14 of about 0.47 microradians. From experience a pivot of 0.47 microradian produces a change in the laser nominal wavelength of about 0.05 pm.

What is needed are improvements which will provide easier, faster and more precise control of laser beam output parameters.

SUMMARY OF THE INVENTION

The present invention provides a smart laser having automatic computer control of pulse energy, wavelength and bandwidth using feedback signals from a wavemeter. Pulse energy is controlled by controlling discharge voltage. Wavelength is controlled by very fine and rapid positioning of an R_{MAX} mirror in a line narrowing module. Bandwidth is controller by adjusting the curvature of a grating in the line narrowing module. Preferred embodiments include automatic feedback control of horizontal and vertical beam profile by automatic adjustment of a prism plate on which beam expander prisms are located and automatic adjustment of the R_{MAX} tilt. Other preferred embodiments include automatic adjustment of the horizontal position of the laser chamber within the resonance cavity. In preferred embodiments, feedback signals from a wavelength monitor are used to position the R_{MAX} mirror. In other preferred embodiments a separate laser beam reflected off the R_{MAX} mirror on to a photodiode array is used to position the mirror.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a prior narrow band art laser configuration.

FIG. 2 shows a preferred embodiment of the present invention.

FIGS. 3A, B and C show the operational principals of a grating bending mechanism.

FIG. 4 shows a prospective view of the bending mechanism.

FIG. 5 shows some of the features of the FIG. 2 preferred embodiment.

FIGS. 6A, B, C and D show other features of the FIG. 2 embodiment.

FIGS. 7A and B show bottom prospective views of the line narrowing module of the FIG. 2 embodiment.

FIG. 8 shows an optical setup for measuring selected beam parameters.

FIGS. 9 and 9A show features of preferred embodiments.

FIG. 10 shows an embodiment with a segmented R_{MAX}.
FIG. 10A shows an embodiment similar to the FIG.10 embodiment.
FIGS. 11, 11A and 11B show features of another preferred embodiment.

FIG. 12 shows a pressure controlled LNP.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention can be described by reference to the drawings.

First Preferred Embodiment

A combination block diagram schematic drawing of a first preferred embodiment of the present invention is shown in FIG. 2. This drawing shows important improvements over the prior art which automate the alignment of the laser chamber and components in order to provide greatly improved instant control of the important laser beam parameters. The new laser frame 5A has added on to it a chamber position stepper motor to automatically adjust the horizontal position of the chamber in the direction 3A. The new LNP 7A includes a prism plate stepper motor 32, an R-max tilt stepper motor 34 and a grating curvature motor 30. All of these stepper motors are controlled by computer controller 24A.

Two-Way Automatic Control of Grating Surface Curvature

A grating curvature stepper motor 30 has been added to control the curvature of grating 16. The system includes a new bending mechanism design 20A which has the capacity to apply either a compressive force to spread apart legs 17A and 17B to create a concave curvature in the lined surface of grating 16 or a tension force to pull together legs 17A and 17B to create a convex curvature in the lined surface of grating 16. Control of motor 30 is provided by computer controller 24.

The basic elements and a functional description of the operation of the grating bending mechanism is shown in FIGS. 3A, 3B and 3C. FIG. 3A shows a grating assembly having a bidirectional control unit attached to it but with no bending force applied to the grating. Shown are grating 16, left end plate 17B, right end plate 17A, compression spring housing 48, left compression spring 50, right compression spring 51, adjustment shaft 44 and piston 49 which is fixedly pinned to adjustment shaft 44. Adjustment shaft 44 comprises threaded length 44A (1/4-28 UNF-2B x 1.38 long) which mates with threaded channel in right end plate 17A. In the FIG. 3A condition, both springs are applying equal compressive force which offset each other or both springs may be unloaded. The curvature of the grating surface is adjusted by turning shaft 44. By screwing shaft 44 into housing

48, left compression spring 50 is compressed against the left side of housing 48 and piston 49 as shown by the two arrows inside housing 48 in FIG. 3B. The compression force pushes rod 44 to the right and housing 48 to the left which has the effect of pushing apart the two end plates 17A and 17B as shown by arrows 56. This has the effect of bending the surface of grating 1 into a concave shape as shown by line 58.

Conversely, by screwing shaft 44 in a direction to drive rod 44 out of housing 48, right compression spring 51 is compressed against the right side of housing 48 and piston 49 as shown by the two arrows inside housing 48 in FIG. 3C. The compressive force pulls rod 44 to the left and pulls housing 48 to the right which has the effect of pulling end plates 17A and 17B together as shown by arrows 57. This has the effect of bending the surface of grating 1 into a convex shape as shown by line 59.

In this preferred embodiment rod 44 has 28 threads per inch and the springs are rated at 52 pounds per inch. Operators are able with this design to make extremely fine adjustments to the curvature of the grating surface.

FIG. 4 is a perspective view of a grating assembly 16A fabricated by Applicants and their co-workers. The assembly is comprised of grating 16, two grating end plates 42 (bonded to grating 16) right bi-directional bandwidth control end plate 17A, lock nut 56, invar base plate 53 bonded to grating 16, alignment rod 44, socket 64, two linear bearings 62, compression spring housing 48, right compression spring 51, two thrust bearings 63, piston 49 pinned to rod 44, left compression spring 50, travel limiting piston 57 pinned to rod 44, radial ball bearing 54, pivot shaft 55 and left bandwidth control end plate 17B.

FIG. 5 is a cutaway drawing of LNP 7A. It shows the two-way curvature-controlled grating assembly 16A. Also shown is grating curvature control stepper

motor 30 for controlling the curvature of the lined surface of grating 16 from concave to convex as explained above with reference to FIGS. 3A, 3B and 3C. FIG. 5 also shows prism plate adjustment motor 32. Motor controls for R_{MAX} mirror 14 are not shown in FIG. 5.

Bottom views of line narrowing package 7A are shown in FIG. 7A (from the front, i.e., looking from the laser toward the LNP) and in FIG. 7B (from the rear). Grating curvature stepper motor 30 is shown mounted on its mounting plate. Prism plate motor is shown at 32 and R_{MAX} tilt motor is shown at 34 and R_{MAX} stepper tuning motor is shown at 15. The R_{MAX} stepper tuning mechanism in this embodiment is substantially identical to a prior art mechanism discussed in the background section. A lever mechanism de-magnifies the linear stepper drive by a factor of 26 to provide for 0.038 micron minimum steps. The beam entrance-exit port for the LNP is shown at 60.

Prism Plate Position Control

Position control of prism plate 13 is depicted in cutaway drawing 5A which also shows prism plate stepper motor 32. Stepper motor 32 is also shown in FIGS. 7A and 7B mounted on its mounting plate. Control of motor 32 is provided by computer controller 24.

Automatic R_{MAX} Tilt Control

R_{MAX} tilt control stepper motor is shown at 34 in FIGS. 7A and 7B and 6A, C and D. The tilt of R_{MAX} mirror 14 is provided by R_{MAX} stepper motor 34 which is also controlled by computer controller 24. The tilt of mirror 14 determines the vertical angle of light reflecting in the resonance cavity.

Wavelength Selection with Tuning Mirror

In this preferred embodiment, wavelength selection is provided with stepper motor 15 setting the pivotal horizontal position of tuning mirror 14 based on direction

from computer controller 24 which utilizes feedback wavelength information from wavemeter 22 in accordance with prior art techniques as discussed in the background section of this specification.

Automatic Chamber Position Control

This first preferred embodiment includes chamber position stepper motor 36 shown in FIG. 2 which automatically adjusts relative to frame 5 (on which is mounted output coupler 4 and line narrowing package 7) the horizontal position of laser chamber 3 (and thus the horizontal position of the gain medium contained therein) in the direction perpendicular to the direction of beam 6.

Controls

Computer controller 24A shown in FIG. 2 is preferably programmed with control algorithms which control motors 36, 32, 34, 30 in addition to 15 in order to maintain beam parameters within desired ranges based on feedback signals from wavemeter 22. A simple approach is to hold all positions constant except one (for example chamber position stepper motor) and scan that item over a predetermined range to seek the position producing the optimum beam performance looking at parameters such as pulse energy output, pulse energy stability and bandwidth. The computer can be programmed to make these scans on operator instruction or to do the scans on a predetermined periodic basis. The computer could also be programmed to make one or more of these types of scans, seeking optimum position, if wavemeter detects a deterioration of any beam quality.

Also during burst mode operation of the laser (where, for example, the laser is operated to produce bursts of pulses such as 300 pulses at a rate of 1000 pulses per second followed by a downtime of 0.3 seconds) beam parameters are known to vary as a function of pulse number (i.e., time after the start of the bursts). In order to moderate or compensate for these variations, the computer controller could be

programmed to adjust one or more of the stepper motors as a function of time after the start of the bursts.

Specific Optimization Techniques

In one preferred performance optimization technique a figure of merit M is defined in order to judge optimum laser performance. Adjustments are then made to maximize the value of the figure of merit. This value is computed using input from sensors which measure the beam in real time. These sensors typically provide values such as energy stability, laser efficiency (energy out for voltage in), bandwidth, beam width, beam symmetry, pointing stability, etc. In general the best figure of merit will combine the several parameters which are most important for determining success in the application, such as lithography exposure. For example if only laser efficiency as measured by pulse energy/charging voltage (E) was considered important to the figure of merit would be

M = pulse energy/charging voltage, or
M = E

If spacial symmetry (in the horizontal direction), SH, is to be judged in addition E, then SH should be measured and given a weighting factor, W_{SH}. Perfect symmetry would be zero. The new formula for figure of merit would then be:

$$M = E - (W_{SH})(SH)$$

Adjustments would then be made to minimize M. Similarly the figure of merit M could be made a function of other parameters such as vertical symmetry (VS), bandwidth (B), wavelength stability (WS) and dose stability (DS). In this case the formula for M would be:

$$M = E - (W_{SH})(SH) - (W_{SV})(SV) - (W_B)(B) - (W_{WS})(WS) - (W_{DS})(DS)$$

Again, the computer is programmed to make adjustments to the stepper positions, measure F, SH, SV, B, WS and DS, apply weighting factors to achieve minimum figures of merit M.

Many techniques are well known for optimizing laser performance where several parameters of the type discussed above are considered. One preferred embodiment is the downhill simplex method which is documented in the book *Numerical Recipes, The Art of Scientific Computing* by W. H. Press, et al., Cambridge University Press 1990 and referenced therein. In brief, a group of initial settings is chosen for the adjustments. There will be a number of configurations (a configuraiton is a set of values for the adjustments) which is one greater than the number of parameters being adjusted. For one iteration, the adjustments are set to each configuration and the figure of merit is measured. The configuration with the worst merit is then rejected and replaced with a new configuration which is closer to the best configuration. As the iterations proceed, the configurations become closer to one another until any one of them may be chosen as the optimum. In early work, Applicants have found that about 10 iterations suffice to locate the optimum. The downhill simplex method is a reliable technique, however, if very rapid convergence is needed other well known techniques could be utilized.

Measurement of Additional Beam Parameters

As indicated in the background section, prior art lithography lasers are provided with a wavemeter which measures pulse energy wavelengths and bandwidth at rapid rates. Typically the parameters are measured for each laser pulse which may be at rates of 1000 Hz to 2000 Hz.

In order to measure various beam parameters, Applicants provided the optical setup described in FIG. 8. An image of the laser beam at the output coupler aperture was relayed optically through lens 70 to a fluorescent screen and beam

parameters including vertical and horizontal symmetry were determined utilizing a CCD camera focused on fluorescent screen 74 as shown in FIG. 8. The fluorescent screen converts the UV light from the laser to visible light which is monitored by the CCD camera. The analog output from the camera is converted to digital with a video frame grabber and the output of the frame grabber is analyzed by a computer processor.

Applicants in conjunction with this work were also able to monitor beam divergence, beam pointing and beam pointing stability with a second beam path through lens 72 as shown in FIG. 8. In this case, lens 72 focuses the laser beam onto the fluorescent screen 74 and is located so that perfectly colluminated light entering the lens would appear as a diffraction limited spot at the fluorescent screen. Therefore, the size of the spot is a measure of the divergence of the beam and movement of the spot is a measure of changes in beam pointing. These additional parameters could be used with the present invention to optimize laser performance taking into consideration these parameters.

Wavelength Control

The typical method of controlling wavelength in laser lithography is for the laser operator to specify a wavelength and the laser control system is set up to automatically produce the specified wavelength with a feedback program. This is usually desirable because during integrated circuit production the laser is typically operated in short bursts of pulses such as 100 pulses at a rate of 1000 pulses per second with downtimes between bursts of a fraction of a second to several seconds. The result is that the wavelength of the beam will fluctuate due to changes in the gain medium and the optical components of the laser system.

In the prior art lithography laser system as shown in FIG. 1, the wavelength of the laser output beam is monitored in output monitor 22 where a combination grating and etalon wavelength monitor monitors the wavelength to an accuracy of about

0.1 pm. The monitor is periodically calibrated against a known absorption line. Such a prior art wavemeter is described in U.S. Patent No. 5,978,334 incorporated herein by reference. For example, the laser operator may program computer controller 24 to control the laser wavelength to 248,321.30 pm. Controller 24 receives wavelength measurements from monitor 22 and uses that information to adjust stepper motor 15 to pivot mirror 14 so that the wavelength is either increased or decreased to maintain the wavelength as measured by monitor 22 at the desisred wavelength of 248,321.30 pm. The smallest increment of movement of this prior art stepper motor 15 will change the output wavelength by about 0.05 pm.

Finer Wavelength Control

A preferred embodiment for providing finer wavelength control is shown in FIG. 9. In this embodiment, prior art stepper motor 15 is utilized to pivot mirror mechanism 14a (about a vertical pivot line as indicated at 80) which includes within it a piezo-electric actuator 14B configured to pivot tuning mirror 14C with one degree of rotary motion (about a vertical pivot line as indicated at 82). Mirror 14C has dimensions of about 1 ½ inch x 3.0 inch and is about 2 ½ inch thick. It weighs about 2 ounces. Small piezo-electric actuators are available which can provide pivot range of 0.1 radians at rates of 5000 Hz with extremely fine precision from supplier such as Physik Instrument for mirrors of this size. These tuning mirror systems are provided with an electronic drive unit which provides high voltage signals to the piezo-electric motors.

In this preferred embodiment, computer controller 24A is programmed to control both stepper motor 15 and piezo-electric unit 14B. Piezo-electric actuator 14B can turn mirror 14C with extremely fine precision so that the laser can be tuned with much more accuracy than the accuracy of the wavemeter which is about 0.1 pm.

In another arrangement as shown in FIG. 9A, the piezo-electric actuator 14D is mounted in series with stepper motor 15 and applies the linear expansion and contraction of the piezo-electric drive to pivot the R_{MAX} mirror about pivot line 80A.

Pre-Tuning

One problem with the prior art wavelength tuning arrangement is that it is a feedback system which means that a few pulses may be required before the laser controls can make the necessary adjustments to produce the wavelength desired. FIG. 11 shows an embodiment especially designed for tuning in advance of laser operation.

A parallel beam 84 from diode laser system 86 is reflected off mirror 14C and is focused by cylindrical lens 88 to a fine line on photo diode array 90 which is used to measure the pivot position of mirror 14C. Information from PDA 90 is used by mirror positioning processor 92 in a feedback configuration to control the positions of stepper motor 15 and piezo-electric actuator 14B to produce the degree of mirror pivot commanded by computer controller 24A. Computer controller 24A is programmed to establish a correlation matrix of PDA output data with wavelength so that it can call for the proper mirror position in advance to produce desired wavelength output.

Parallel beam 84 may be provided by diode laser system 86 comprising diode laser 94 working at 670 nm coupled to a single-mode fiber 96 with a core diameter of about 2.5 micron. Light exiting fiber 96 is collimated by an aspheric lens 98 into parallel beam 84.

The focal length of lens 98 is about 20 mm so that it creates a beam 84 with a diameter of about 5 mm. Divergence of this beam is about:

$$\theta = 1.22\frac{\lambda}{D}$$

where λ is the 670 nm wavelength and D is the beam diameter of 5 mm, so the divergence is about $\theta = 1.63 \times 10^{-4}$ radian. This low divergence beam is focused by lens 88 onto diode array 90 at a distance of about 500 mm. The spot size at the PDA is about 82 micron. The preferred PDA has 2048 pixels at 14 micron spacings. Thus the spot covers about 6 pixels.

Laser operators desire to control the laser to a desired wavelength with an accuracy of ±0.1 pm or better. A wavelength change of one picometer for a KrF laser corresponds to a change in the pivotable position of mirror 14 of about 9.9 μ rad.

The distance between mirror 14 and PDA 90 is about 300 mm. A 9.9 μ rad tilt of mirror 14 will produce a 5.94 micron shift in the beam spot on PDA 90. The spot thickness is about 82 microns. To try to achieve an accuracy of 0.6 μ shift (correspondingly to 0.1 pm wavelength shift) will require monitoring the intensity values of pixels along the steep part of the beam spot (near the half maximum part of the spot). Processor 92 is preferably programmed to do that. Each pixel has an intensity response of 256 levels on commercially available low cost PDA arrays. Accuracy may also be improved by using averages of several pixels on the steep part of the spot and further improved by averaging a large number of intensity values over available time intervals.

Another preferred approach is indicated by FIG. 11A. Here an intermediate fixed mirror 100 permits the beam to make four bounces off mirror 14C which multiplies the shift by a factor of 4 to 24 microns shift per picometer wavelength. Thus, a 0.1 pm variation would correspond to a shift in the beam spot of 2.4

microns which would be much easier to see in the change in pixel intensity values on the steep edge of the spot.

Chirp

The change in wavelength with time is referred to in the industry as "chirp" or "wavelength chirp". These changes may occur very rapidly such as on time scales of 0.001 second or less. As indicated above, chirp can be caused by many factors such as thermal effects and acoustic effects in the chamber and optical elements. Mostly chirp is undesirable and the very fast control of wavelength provided by the present invention permit it to be used to minimize the chirp. In addition, there may be situations when some controlled chirp is desirable and it can be programmed in using computer controller 24A and processor 92. The main advantage of the system shown in FIGS. 11, 11A and 11B is that the mirror position can be set in advance of laser operation based on historical calibration data.

The reader should understand that in a gas discharge laser operating of pulse rates of 1000 Hz to 5000Hz, the laser gas is circulating at speeds of up to 100 m/s between the electrodes which are periodically dumping about 3 kilowatts into a small quantity of laser gas, and the prisms and other optical components are being subject to ultraviolet light pulses with average energies varying from zero watts to about 50 watts. Thus, thermal and other effects can cause very slight changes in the wavelength which the operator may be attempting to conrol to an accuracy of 0.1 pm or less. The embodiment shown in FIG. 11 permits the operator to adjust tuning mirror 146 to compensate for distortions in the wavelength caused by these effects.

If an undesirable chirp pattern is detected corresponding to a particular mode of laser operation, the computer processors 24A and 92 can be programmed to control the tuning mirror 14C in advance to minimize the chirp.

Deformable Mirror

FIG. 10 shows another preferred embodiment of the present invention. In this case the embodiment is similar to the FIGS. 9 and 11 embodiments except that the mirror 14C in the FIGS. 9 and 11 embodiments is segmented into five segments 14C 1, 2, 3, 4 and 5. Each segment is controlled by its own piezo-electric driver. Preferably the piezo-electric elements provide tilt, tip and piston so that the mirrors can be pointed at the required angle and also if the mirrors are offset phase-wise that the offset is multiples of wavelengths. Such a segmented mirror is described in U.S. Patent No. 4,944,580 issued July 31, 1990, which is incorporated herein by reference. Because the individual segmented mirrors are much lighter much faster control as possible. Current piezo-electric technology permit pivotable adjustments at the rates up to 10,000 Hz.

As shown in FIG. 10A the position of these mirrors can be monitored using a mercury light source from lamp 114 through slit 116 which is collimated with lens 118 and reflected off mirror 120 positioned above the laser beam. The Hg beam is expanded through beam expander prisms 8, 10 and 12 and focused by mirror array 122 onto PDA array 124.

Piezo-electric driven deformable mirrors of the type shown in FIG. 10 are available from many suppliers such as ThermoTrex Corporation, San Diego, California.

Pressure Modulation

Another method of providing very fine tuning of wavelength is by controlling the gas pressure in the LNP. The LNP is preferably purged with nitrogen. In the past the nitrogen pressure has been maintained constant at a pressure very slightly in excess of atmospheric pressure. A change in the nitrogen pressure changes the index of refraction of which changes very slightly the incident angle on the

grating. Since the purge flow is a continuous flow through the LNP, the pressure could be changed using a control valve on the inlet purge line or on an outlet purge line. The resulting response would be relatively slow. Rapid changes in pressure could be provided as shown in FIG. 12 using a proportional solenoid actuator 110 and a bellows 112. Other purge gases such as helium could be used instead of nitrogen.

Although this invention has been disclosed and illustrated with reference to particular embodiments, the principals involved are susceptible for use in numerous other embodiments which will be apparent to persons skilled in the art. For example, each of the stepper motors could be replaced with alternative positioner units such as, ac or dc motors or hydraulic or pneumatic positioners. Many methods of controlling the positioners other than the suggested computer programs could be utilized. One or more stepper motors could be applied to the output coupler to automatically position it using similar techniques as described above for the R_{MAX} mirror. Three strong permanent magnets could be used in the place of the two compression springs with one of the magnets replacing the piston as shown in FIG. 6. Magnet 60 is fixed to rod 4 and magnets 62 and 64 are fixed to housing 8. Rod 4 passes through holes in magnets 62 and 64. The effect of screwing rod 4 into and out of housing 8 is substantially the same as described above. The curvature of the grating could be accomplished using any of a large number of techniques. For example, compression or tension could be applied at a number of points to create virtually any shape desired and these shapes could be subject to feedback computer control. Mirror 14 could be other types of deformable mirrors such as smooth deformable mirrors. The beam expander could be an all reflective beam expander. The invention is therefore to be limited only as indicated by the scope of the appended claims and their legal equivalents.

CLAIMS

We claim:

1. A narrow band electric discharge laser for producing an output laser beam said laser comprising:

   A) a laser frame;
   B) a laser chamber adjustably mounted in said frame;
   C) a laser gas contained within said chamber;
   D) two elongated spaced apart electrodes contained within said chamber, said electrodes and laser gas between them defining a gain medium;
   E) a line narrowing module comprising a beam expander, a tuning mirror and a grating;
   F) a fine tuning means for adjusting said output wavelength with a precision of less than 0.1 pm;
   G) a wavemeter for detecting laser output beam wavelength;
   H) a computer controller.

2. A laser as in Claim 1 wherein said tuning means comprises at least one piezo-electric actuator for pivoting said tuning mirror.

3. A laser as in Claim 1 wherein said tuning means comprises a pressure control means for increasing or decreasing gas pressure in said line narrowing module.

4. A laser as in Claim 1 wherein said tuning means comprises a stepper motor and at least one piezo-electric actuator.

5. A laser as in Claim 1 wherein said tuning mirror is a deformable mirror.

6. A laser as in Claim 1 wherein said tuning mirror is a segmented mirror comprising a plurality of mirror segments.

7. A laser as in Claim 1 and further comprising a mirror position detection system for detecting pivot positions of said tuning mirror.

8. A laser as in Claim 7 wherein said mirror position detection system comprises a position detection light source directed at said mirror and a detector array for detecting reflection from said mirror.

9. A laser as in Claim 8 wherein said light source comprises a diode laser.

10. A laser as in Claim 8 wherein said light source comprises a mercury lamp.

11. A laser as in Claim 6 and further comprising a mirror position detection system for detecting positions of each mirror segment.

12. A laser as in Claim 1 and further comprising a chamber positioner unit for positioning said chamber in a horizontal direction so that said gain medium is in a desired position with respect t the resonance cavity.

13. A smart laser as in Claim 2 wherein the computer controller is programmed to control said chamber positioner unit to position said chamber based on feedback information from said wavemeter.

14. A smart laser as in Claim 1 wherein said prism beam expander comprises a plurality of prisms disposed on a prism plate, and further comprising a prism plate positioner unit for positioning said prism plate.

15. A smart laser as in Claim 4 wherein said computer controller is programmed to control said prism plate positioner unit to position said prism plate based on feedback information from said wavemeter.

16. A smart laser as in Claim 1 and further comprising an R_{MAX} tilt positioner to tilt said R_{MAX} mirror to control vertical spatial parameters of said output laser beam.

17. A smart laser as in Claim 6 wherein said computer controller is programmed to control said tilt positioner to tilt said R_{MAX} mirror based on beam information from said wavemeter.

18. A smart laser as in Claim 1 wherein said beam expander comprises a plurality of prisms disposed on a movable prism plate and further comprising:

A) a chamber positioner unit for positioning said chamber in a horizontal direction upon control signals from said computer controller;

B) a prism plate positioning unit for positioning said prism plate upon control signals from said computer controller;

C) an R_{MAX} tilt positioner to tilt said R_{MAX} mirror based upon control signals from said computer controller; and

D) an R_{MAX} pivot positioner to pivot said R_{MAX} mirror to adjust nominal wavelength of said output beam based on control signals from said computer controller.

19. A smart laser as in Claim 1 wherein said grating curvature positioner comprises a stepper motor.

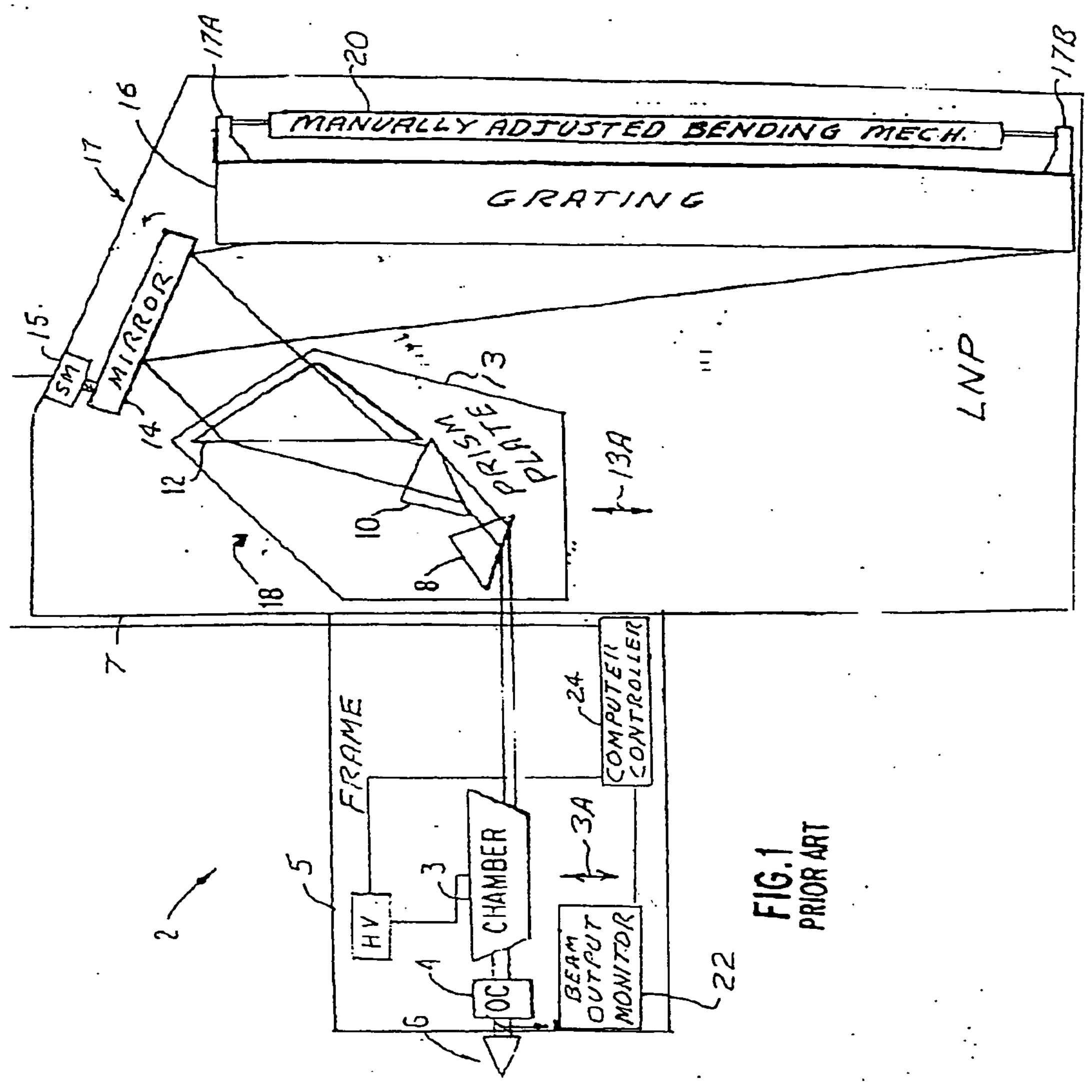


FIG.1
PRIOR ART

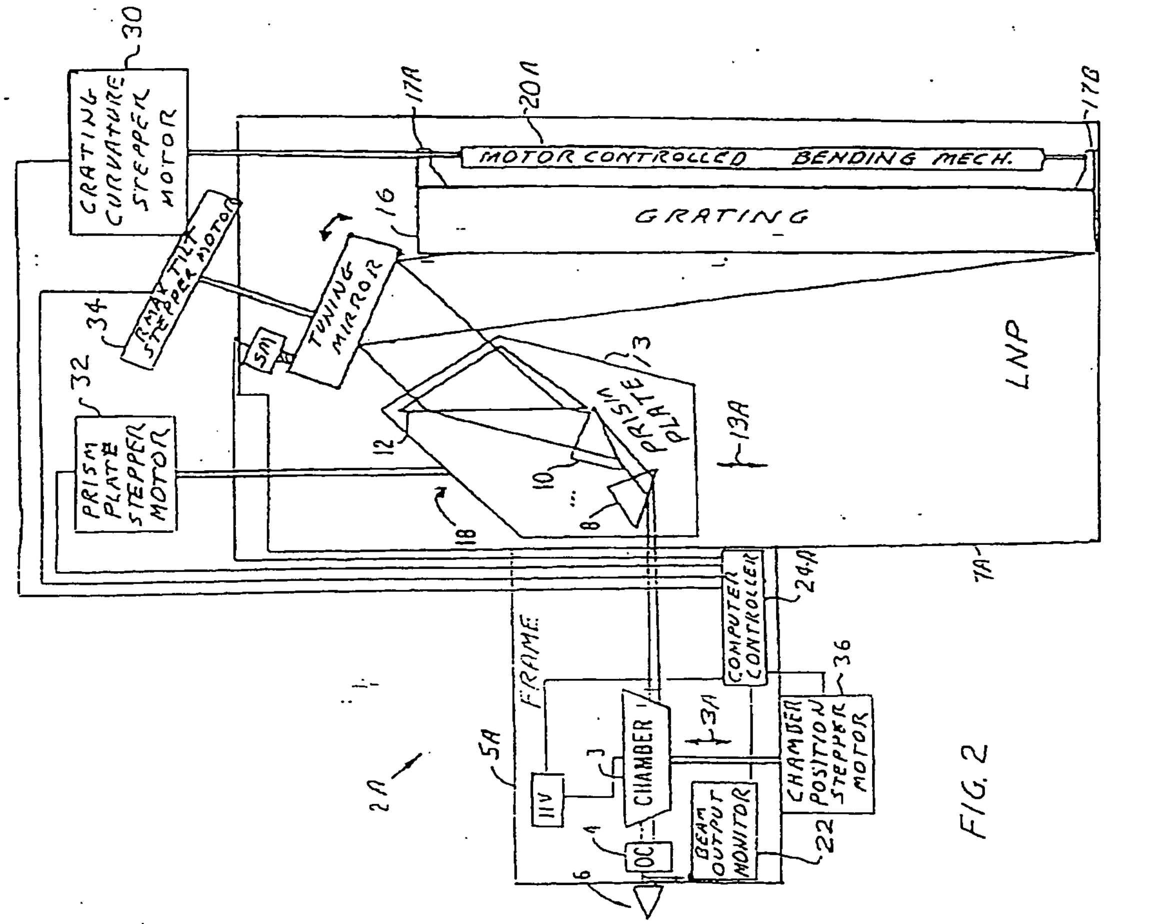
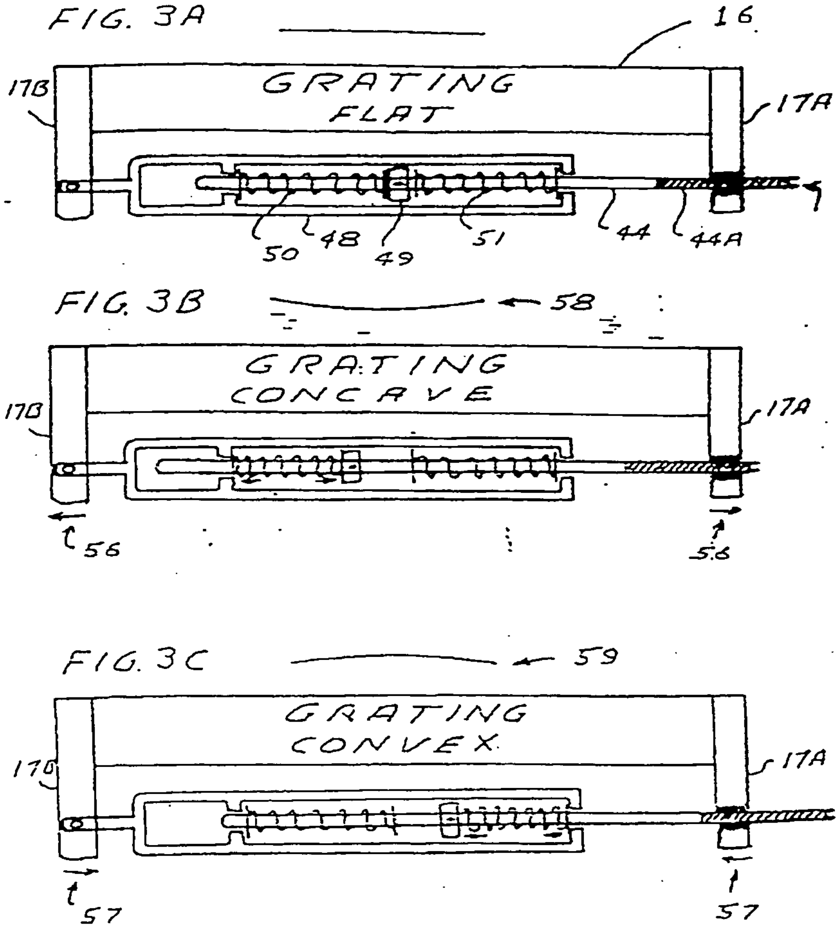

GRATING CURVATURE STEPPER MOTOR
30
17A
20A
17B
MOTOR CONTROLLED BENDING MECH.
GRATING
16
TUNING MIRROR
RMAX TILT STEPPER MOTOR
34
SM
PRISM PLATE
13
13A
LNP
32
PRISM PLATE STEPPER MOTOR
12
10
8
18
7A
24A
COMPUTER CONTROLLER
FRAME
36
CHAMBER POSITION STEPPER MOTOR
3A
CHAMBER
3
HV
5A
2A
OC
4
BEAM OUTPUT MONITOR
22
6

FIG. 2

FIG. 3A

FIG. 3B

FIG. 3C



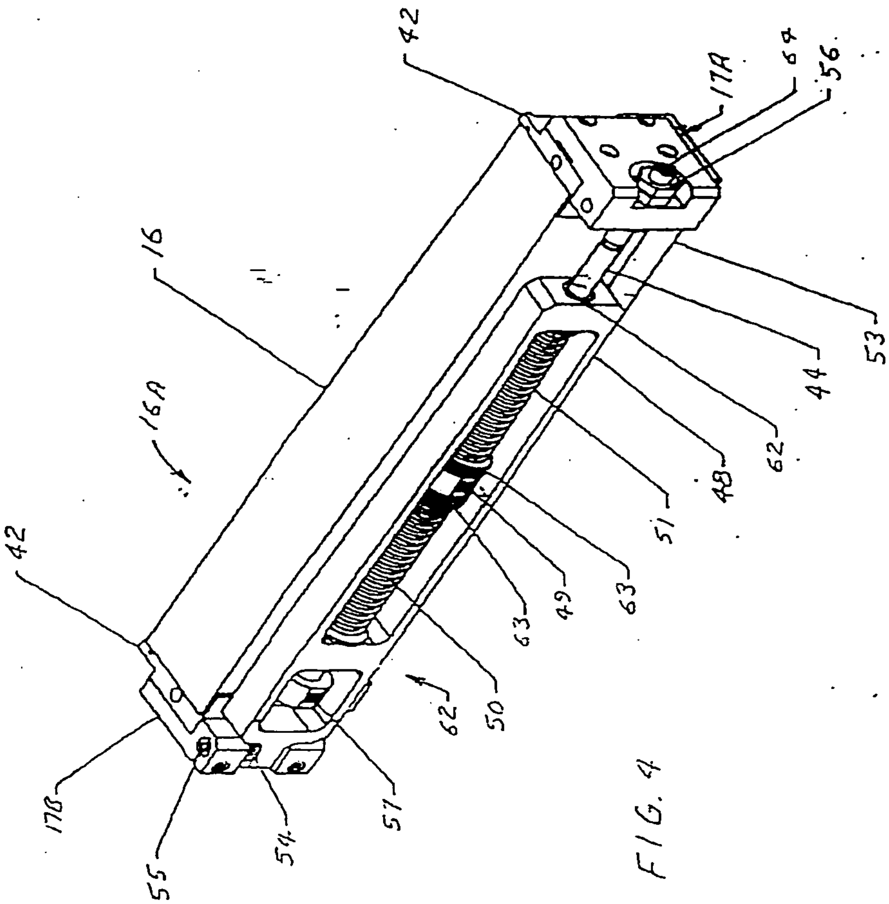


FIG. 4

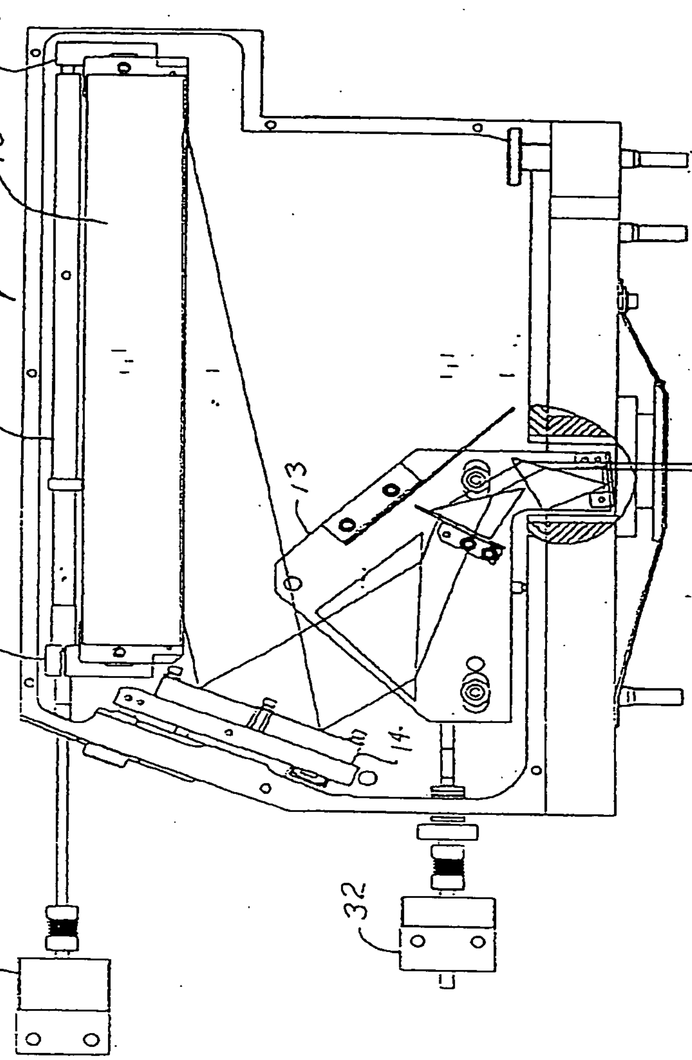
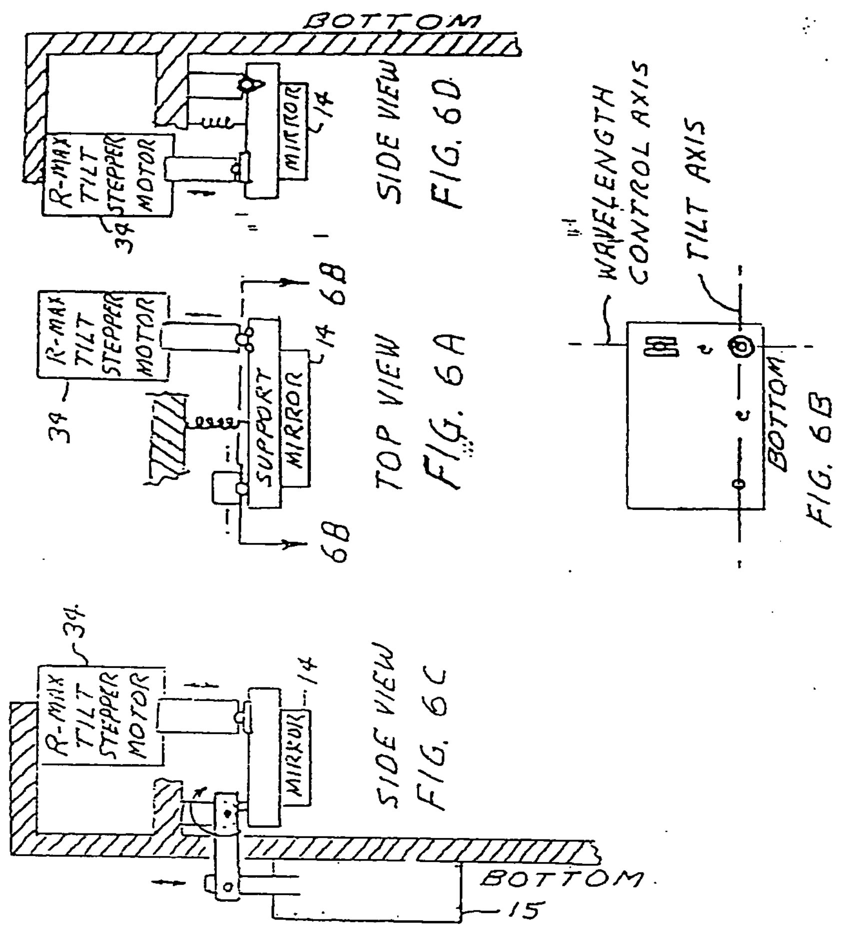
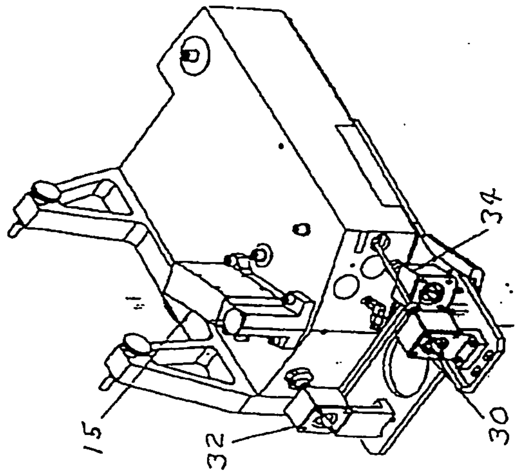
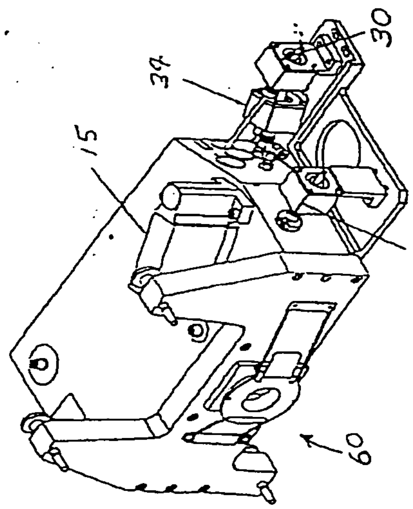


FIG. 5


BOTTOM
R-MAX TILT STEPPER MOTOR
34
MIRROR
14
SIDE VIEW
FIG. 6D
R-MAX TILT STEPPER MOTOR
34
SUPPORT
MIRROR
14
6B
6B
TOP VIEW
FIG. 6A
WAVELENGTH CONTROL AXIS
TILT AXIS
BOTTOM
FIG. 6B
R-MAX TILT STEPPER MOTOR
34
MIRROR
14
SIDE VIEW
FIG. 6C
BOTTOM
15



BOTTOM VIEW
FROM BACK
FIG. 7B



BOTTOM VIEW
FROM FRONT
FIG. 7A

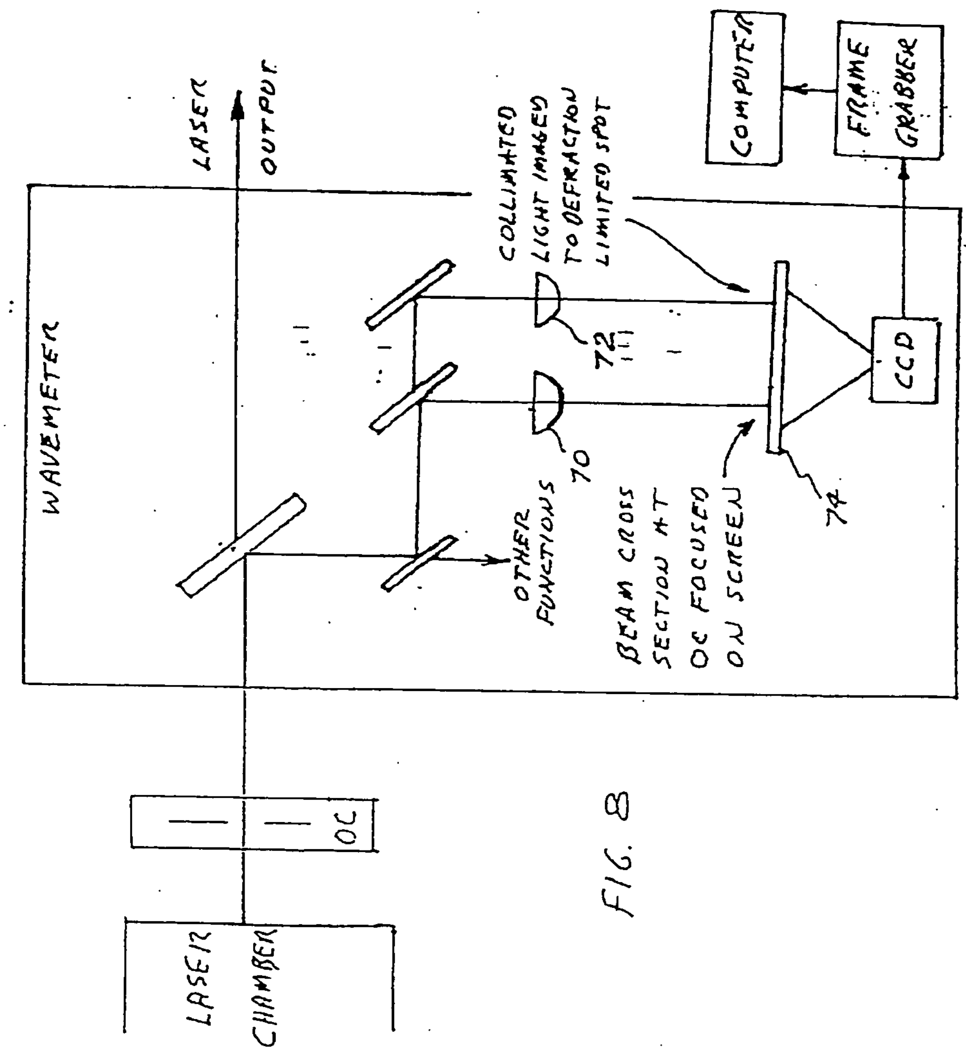

LASER OUTPUT
WAVEMETER
COLLIMATED LIGHT IMAGED TO DEFRACTION LIMITED SPOT
COMPUTER
FRAME GRABBER
72
70
CCD
74
OTHER FUNCTIONS
BEAM CROSS SECTION AT OC FOCUSED ON SCREEN
OC
LASER CHAMBER

FIG. 8

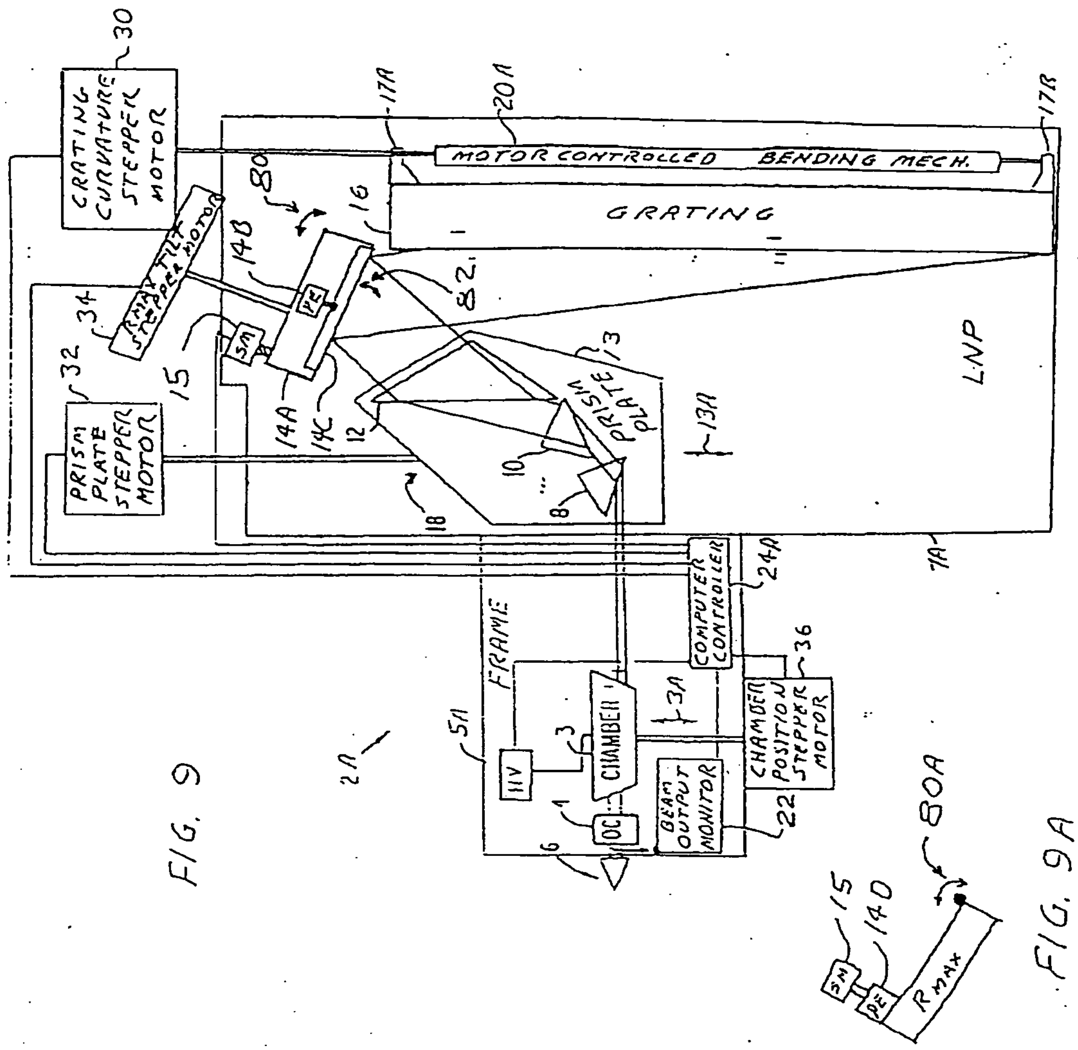

GRATING CURVATURE STEPPER MOTOR
30
20A
17A
17B
MOTOR CONTROLLED BENDING MECH.
GRATING
16
80
82
RMAX TILT STEPPER MOTOR
34
14B
PE
SM
15
32
PRISM PLATE STEPPER MOTOR
14A
14C
12
13
PRISM PLATE
13A
10
8
18
LNP
7A
COMPUTER CONTROLLER
24A
36
CHAMBER POSITION STEPPER MOTOR
FRAME
5A
3A
3
CHAMBER
HV
1
OC
BEAM OUTPUT MONITOR
22
6
2A
80A
15
14D
SM
PE
RMAX

FIG. 9

FIG. 9A

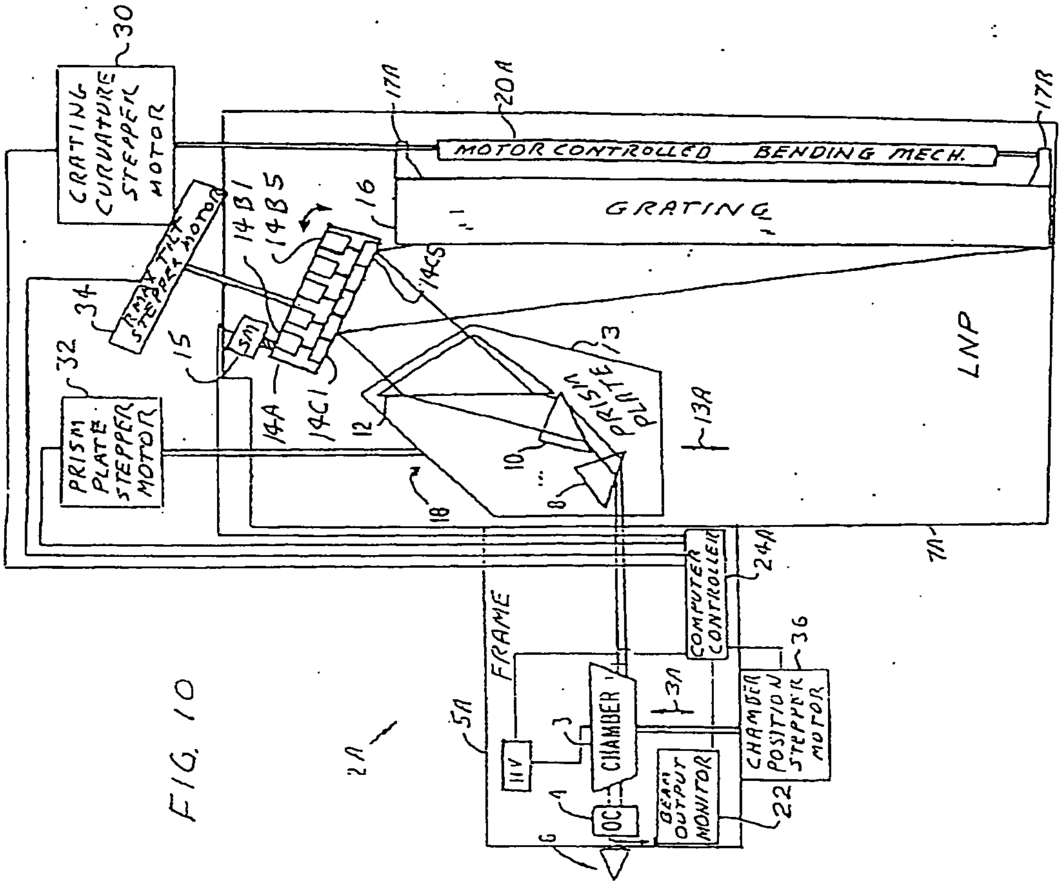
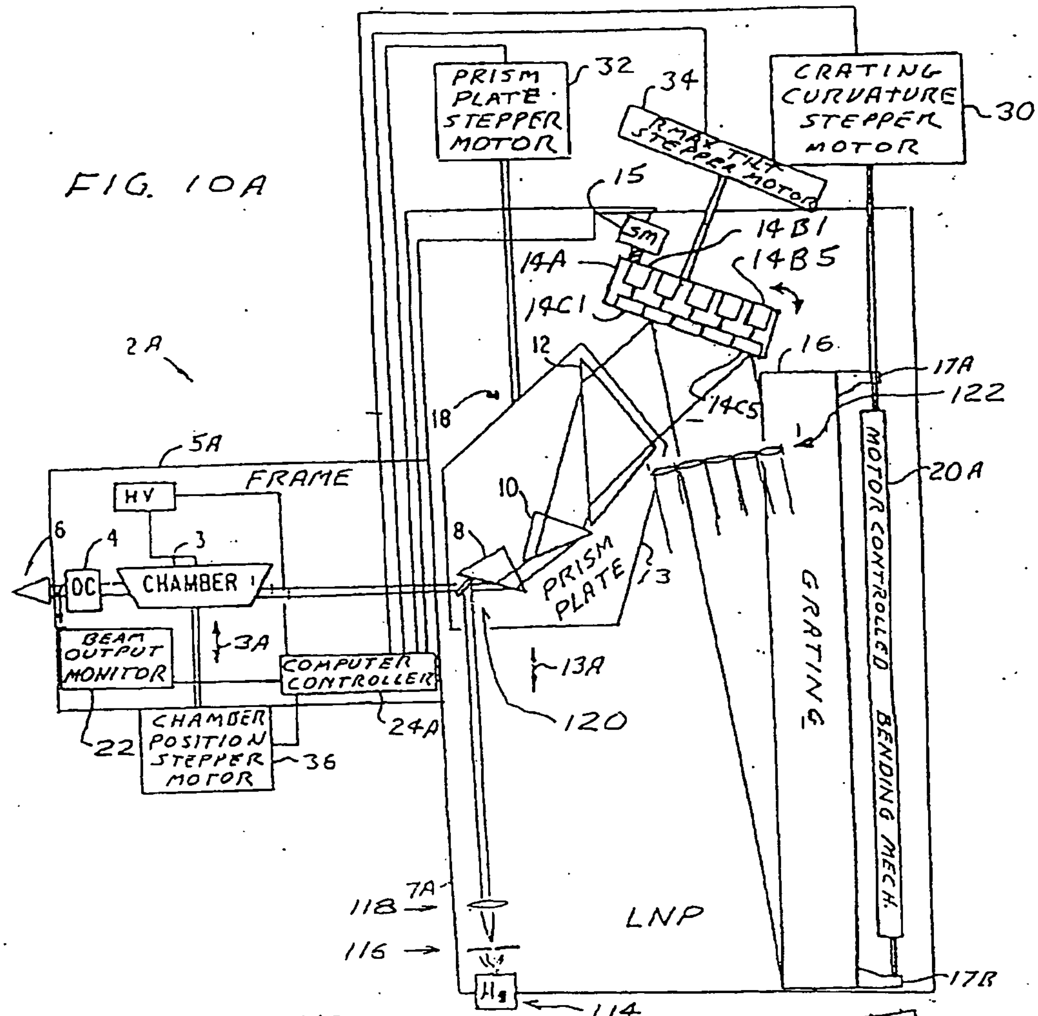

GRATING CURVATURE STEPPER MOTOR
MOTOR CONTROLLED BENDING MECH.
GRATING
RMAX TILT STEPPER MOTOR
PRISM PLATE STEPPER MOTOR
PRISM PLATE
LNP
FRAME
CHAMBER
HV
OC
BEAM OUTPUT MONITOR
COMPUTER CONTROLLER
CHAMBER POSITION STEPPER MOTOR
SM

FIG. 10

FIG. 10A



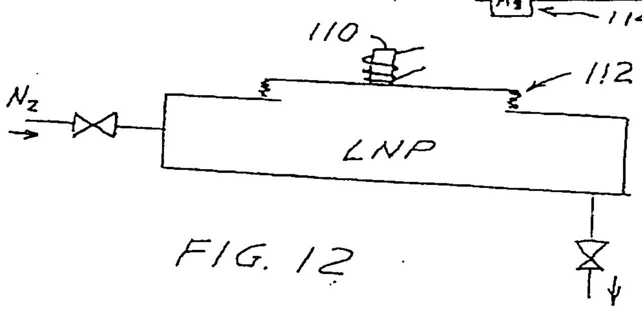


FIG. 12

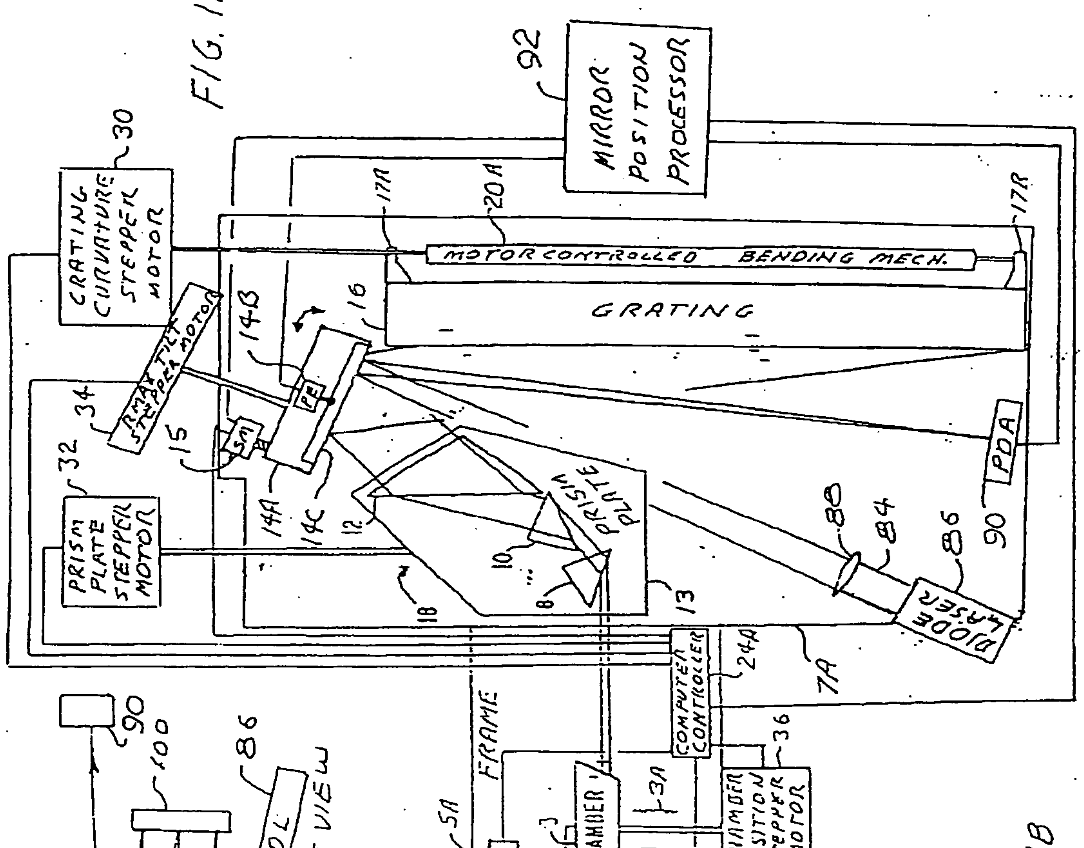


FIG. 11

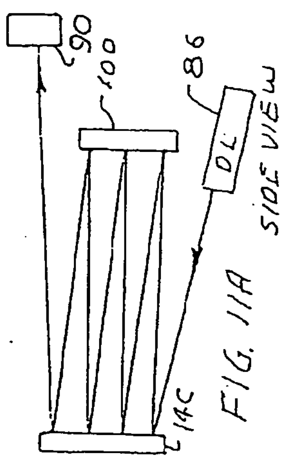


FIG. 11A
SIDE VIEW

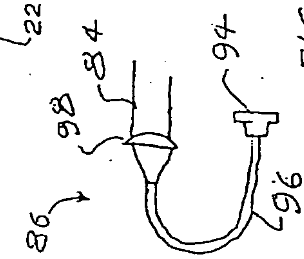


FIG. 11B

ABSTRACT OF THE DISCLOSURE

A smart laser having automatic computer control of pulse energy, wavelength and bandwidth using feedback signals from a wavemeter. Pulse energy is controlled by controlling discharge voltage. Wavelength is controlled by very fine and rapid positioning of an R_{MAX} mirror in a line narrowing module. Bandwidth is controller by adjusting the curvature of a grating in the line narrowing module. Preferred embodiments include automatic feedback control of horizontal and vertical beam profile by automatic adjustment of a prism plate on which beam expander prisms are located and automatic adjustment of the R_{MAX} tilt. Other preferred embodiments include automatic adjustment of the horizontal position of the laser chamber within the resonance cavity. In preferred embodiments, feedback signals from a wavelength monitor are used to position the R_{MAX} mirror. In other preferred embodiments a separate laser beam reflected off the R_{MAX} mirror on to a photodiode array is used to position the mirror.